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THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

EDITED BY

GEORGE E. HALE
Mount Wilson Observatory of the Carnegie Institution of Washington

EDWIN B. FROST
Yerkes Observatory of the University of Chicago

HENRY G. GALE
Ryerson Physical Laboratory of the University of Chicago

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ON THE MEASUREMENT OF POLE-EFFECT AND ITS CONNECTION WITH MAGNETIC SEPARATION *H. Nagaoka* 329

THE STRUCTURE OF THE BISMUTH LINES *H. Nagaoka and Y. Sugiura* 339

THE MUTUAL ACTION OF ADJACENT PHOTOGRAPHIC IMAGES *Frank E. Ross* 349

OBSERVATIONS OF THE NEBULAR LINES IN THE SPECTRUM OF THE LONG-PERIOD VARIABLE STAR R AQUARII *Paul W. Merrill* 375

ON SYSTEMATIC DISPLACEMENTS OF LINES IN SPECTRA OF VENUS *Charles E. St. John and Seth B. Nicholson* 380

BRIGHT AND DARK NEBULAE NEAR ζ ORIONIS PHOTOGRAPHED WITH THE 100-INCH HOOKER TELESCOPE *John C. Duncan* 392

INDEX 397

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WITH THE COLLABORATION OF

JOSEPH S. AMES, Johns Hopkins University
ARISTARCH BELOPOLSKY, Observatoire de Poulkova
WILLIAM W. CAMPBELL, Lick Observatory
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THE
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VOLUME LIII JUNE 1921 NUMBER 5

ON THE MEASUREMENT OF POLE-EFFECT AND ITS CONNECTION WITH MAGNETIC SEPARATION

By H. NAGAOKA

ABSTRACT

Method of measuring minute shifts of spectral lines.—By using a *displaceable slit* and by interposing an echelon or Lummer-Gehrcke plate between the source and the spectrograph, the same lines from two parts of an arc or from any two sources may be photographed side by side and shifts of one or two milli-angstroms can be determined from the displacement of the interference points, if the lines are sharp and are not interfered with by neighboring lines. The method could be used for the *comparison of spectra of isotopes* or for a study of the *pole-effect*. As a comparison source, the vacuum discharge from a lime cathode of carbon is recommended as both intense and free from pole-effect.

Relation of pole-effect to Zeeman effect for iron lines.—As Gale and Adams have found a relation between pressure-shift and magnetic separation for lines of the same type, it might be expected that the pole-effect also varies with the Zeeman effect; but a study of the available data shows that for positive shifts of pole-effect there is no correlation and for negative shifts the magnetic separation, if anything, seems to decrease as the amount of the shift increases.

The so-called "pole-effect" is evidently a complicated phenomenon, in which the shift of the spectrum lines due to pressure, the length of the arc, the velocity of electrons and of ions, the potential gradient near the electrodes, and other minor causes are involved. These various elements contributing to the pole-effect act simultaneously, and at present it seems next to impossible to separate and identify them. According to the investigations of

St. John and Babcock,[1] the Pfund arc with carbon as the negative pole is almost free from the pole-effect, and may be used for the comparison of wave-lengths; in fact it is planned to use the iron lines as secondary standards. The practical need of determining wave-lengths to a thousandth of an angstrom, makes necessary the easy measuring of pole-effect, to determine whether or not the required exactness can be obtained with the arc. By the method employed by St. John and Babcock, exact measurement can be obtained, but the apparatus requires much space; a far simpler arrangement may be applied practically for testing the presence of pole-effect.

The method which I have employed may be called that of slit-displacement. The narrow vertical slit of a spectroscope is so constructed that by means of a fine screw, the slit may be shifted smoothly by nearly the amount of its width in a horizontal direction, so that in one position of the slit the spectrum of the standard arc can be photographed, and in the shifted position that of the arc to be tested. The spectroscope must of course be of high resolution; it may be a Fabry-Perot interferometer, a Lummer-Gehrcke plate, or an echelon grating, all of which have in general resolving powers greater than a six-inch grating. For this purpose, the light from the portion of the arc to be examined is made to fall on the interferometer; and the transmitted light is received on the collimator of a spectrograph with the displaceable slit before mentioned. The spectrograph which I used was provided with a Cornu prism of quartz, the objective of the collimator and of the camera lens being made of the same material. Very good results were obtained with a Lummer-Gehrcke plate of quartz. The photographs were tolerably sharp and extended to the ultra-violet. On a single photographic plate, a spectral region extending over 1000 angstroms can be obtained with good definition.

The light to be measured is focused on the horizontal slit of an echelon spectroscope, with the edges of the plates horizontal; after passing the echelon, the light is brought to a focus and then projected, by means of a micro-planar, on to the displaceable slit of a prism spectrograph, and the spectrum photographed. The

[1] *Astrophysical Journal*, **46**, 138, 1917.

spectrum consists of a series of interference points arranged in vertical lines, which in the absence of the echelon grating would correspond to continuous lines. On account of the thickness (nearly 36 cm) of the glass echelon grating used in the experiment, it was not possible to go far into the ultra-violet region. By using a photographic objective of sufficiently long focus, it was possible to obtain spectrograms with sufficiently large intervals for successive spectra to show the pole-effect. The interval for successive orders of spectra in the foregoing experiment was about 0.400 A for λ 5000, so that it was easy to observe a shift of 0.002 A. With the quartz plate, the interval was about one-half of the above amount; consequently the measurement could be pushed to about 0.001 A. In all these experiments, the great drawback was the indefiniteness of the interference points; in other words, the lines from an iron arc *in air* are broader than those from a vacuum arc; the consequence is that the position of the center of the interference points is difficult to measure, and the error of observation is thus not very small. On the contrary, the same experiment with the iron-iron arc at 110 volts, or by cathode bombardment, both in vacuum, gives extremely well-defined interference points, whose mean position can be determined with great accuracy. In this respect, the arc in air is far inferior to that in vacuum, and is also subject to various fluctuations, which cannot at present be avoided, so long as it is operated in air.

The foregoing method is open to the objection that the source under investigation and the comparison spectrum cannot be photographed simultaneously. This can, however, be in a great part eliminated by photographing the lines to be compared in successive steps in reverse order and by taking the mean. The echelon grating is more sensitive to a change of temperature than the Lummer-Gehrcke plate, but as it takes only a few minutes for each exposure, the variation arising from the change of temperature, if due precaution be taken, is generally negligibly small.

Apart from the pole-effect, the process sketched above will be of some importance in comparing the spectra of isotopes, in which the difference in wave-length, such for example as ordinary lead and radio-lead, is according to Aronberg and Merton of the order

of a few milli-angstroms. For very fine measurements, the source of light obtained by cathode bombardment of the elements is strongly to be recommended, for otherwise the appearance of interference points is rather vague and ill-defined, so that the comparison is not free from errors of setting. As the question of the isotopes is at present attracting the attention of chemists and physicists, it will not be out of place to mention a method which, though originally intended for the purpose of studying pole-effect, will be useful for the spectral investigation of the isotopes, and other problems of similar nature, in which the determination of a small difference in wave-length is aimed at. The accompanying photographs (Plate VII) show a comparison of an iron arc at the center and at the negative pole, and were obtained by the above-mentioned process with a Lummer-Gehrcke plate of quartz.

In the upper figure, the left column of interference points refers to the center, and the right column to the negative pole of 6-mm arc. The shift of the lines is indicated by the inclination of the line joining the neighboring points, and the sense of the shift is also apparent from that of inclination. In the figure, the positive shift is given by a clock-wise rotation. Unfortunately the dispersion of the quartz prism is not large enough to separate lines lying close together, so that the shift is masked by the presence of neighboring lines. For applying the method successfully, higher dispersion is necessary to prevent the intrusion of other lines. The interval between successive interference points is 0.133 A for λ 4000, so that the shift can be easily determined to a few thousandths of an angstrom.

The lower figure shows an iron spectrum excited by a lime cathode. The interference points are more distinct than those given by an ordinary arc, but many lines show unsymmetrical reversals. The position of the points can however be determined with greater accuracy, so that for purposes of exact measurement of wave-length the cathode excitation will be found to give definite results, as many causes contributing to pole-effect are eliminated by placing the source of light in a high vacuum.

Let us now pass to the second part of the discussion. However complex the causes of pole-effect may be, an apparent connection

PLATE VII

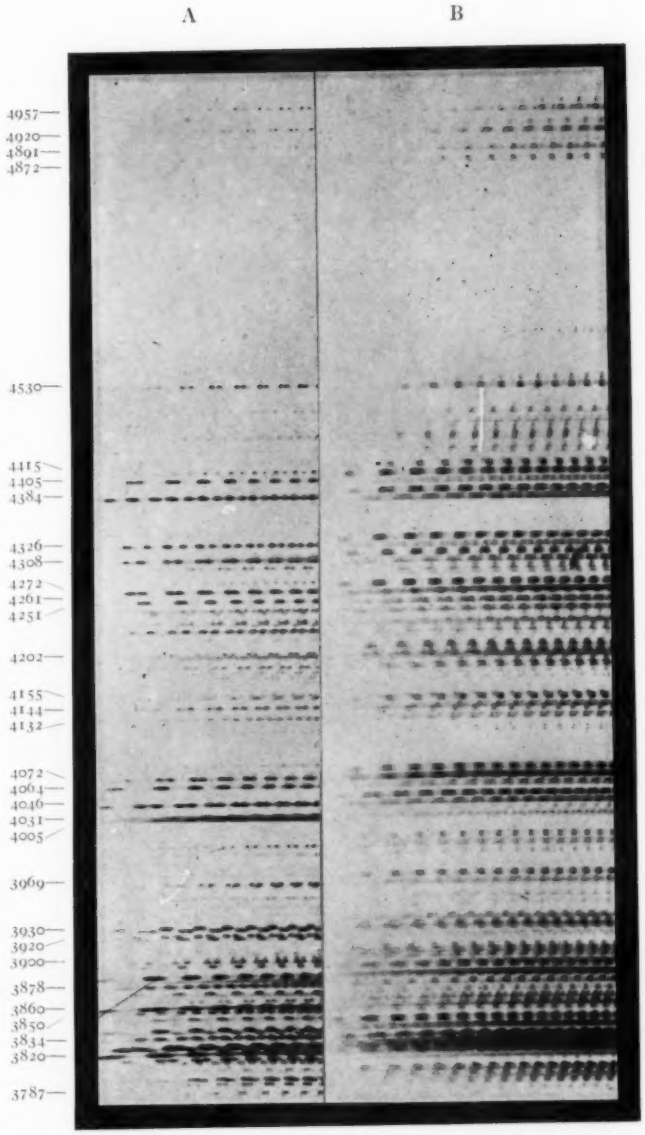

A
B
4957
4920
4891
4872
4530
4415
4405
4384
4326
4308
4272
4261
4251
4202
4155
4144
4132
4072
4064
4046
4031
4005
3969
3930
3920
3900
3878
3860
3850
3834
3820
3787
Negative Pole
Center of Arc

TABLE I

Wave-Length	Type	n	p	Pole-Effect
3676.88 ?	3	1.746	.....	+ 6
3697.44	6 ?	.....	2.522	+ 6
3703.70	3	.....	.....	+ 5
3721.51 ?	3	2.470	.....	+ 5
3735.33	4 ?	3.384	1.190	+ 5
3787.60	8	1.508 0.763	0.767	+ 7
3811.01 ?	3	1.756	.....	+10
3814.79 ?	5	? 1.250	.....	+12
3817.65	3	1.159	.....	+30
3830.87	3	.....	.....	+ 8
3920.85 ?	3	2.271	.....	+ 8
3928.09	3	2.282	.....	+10
3941.29 ?	3 ?	2.962	.....	+14
3947.00	4 ?	1.560	.....	+ 4
3948.11	3	1.585	.....	+ 9
3957.03	3	1.807	.....	+18
3963.11	?	.....	.....	+12
3965.44 ?	.....	.....	.....	.....
3976.62	3	2.019	.....	+ 4
4018.28	3	1.784	.....	+ 4
4024.75	3 ?	1.290	.....	+13
4030.51	6 ?	1.685	.....	+11
4072.52 ?	3	1.025	.....	+ 8
4073.76	3	2.169	.....	+ 8
4083.78 ?	.....	.....	.....	.....
4084.51	3 ?	1.798	.....	+ 7
4101.27 ?	3	1.796	.....	+ 8
4104.13 ?	.....	.....	.....	+ 8
4109.07	.....	.....	.....	+ 4
4118.90 ?	3	1.597	.....	+10
4150.28 ?	3 ?	2.305	.....	+18
4153.92	3	2.196	.....	+12
4154.82	3	2.230	.....	+ 4
4157.80 ?	6 ?	2.400	.....	+18
4158.81	?	3.405	.....	+14
4187.05	7 ?	2.253	.....	+ 8
4187.81	3	2.292	.....	+10
4191.44	7	3.073 1.502	0.790	+10 I.S.
4195.34	3	1.818	.....	+ 9
4196.22	3	2.039	.....	+11
4198.31	3	2.172	.....	+10
4210.36	3	4.547	.....	+ 6
4217.56	6 ?	2.259	.....	+ 8
4222.22	3	2.665	.....	+ 6A
4225.46	6	2.508	.....	+ 4
4227.45	3	1.728	.....	+14
4233.16	6 ?	1.574	.....	+ 7
4233.61	9	4.351 3.068 1.478	0.780	+10 I.S.
4235.95	3	2.519	.....	+ 9

TABLE I—*Continued*

Wave-Length	Type	n	p	Pole-Effect
4238.83.....	3	1.781	.....	+11
4247.44.....	3	1.973	.....	+11
4250.13.....	7 ?	2.115	.....	+10
4260.49.....	3	2.330	.....	+12
4271.17.....	3	2.160	.....	+10
4299.25.....	3	2.197	.....	+ 9
4407.71.....	3 ?	3.247	.....	+11
4462.01 ?.....	3	2.185	.....	+20
4469.39.....	3 ?	2.192	.....	+ 8
4531.64.....	6 ?	1.939	0.506	+ 6
4611.29 ?.....	3	3.067	.....	+ 6
4637.52.....	3 ?	.....	.....	+12
4654.64.....	3 ?	2.506	.....	+ 7
4668.15.....	6 ?	1.661	.....	+13
4707.29.....	3 ?	1.647	.....	+12
4736.79.....	6 ?	1.898	.....	+12
4859.76.....	8	1.194	1.143	+14 I.S.
4891.50.....	?	1.620	.....	+12
4903.32.....	6 ?	3.600	0.632	+ 9 I.S.
4919.01.....	6 ?	2.441	1.115	+16 I.S.
4920.52.....	3 ?	1.845	.....	+13
4923.94.....	7 ?	2.537	.....	+46
4938.83.....	4 ?	3.023	.....	+18
4946.40.....	3	1.968	.....	+24
4957.31.....	6 ?	2.565	0.773	+14
4957.61.....	3 ?	2.307	.....	+14
4966.10.....	3	2.134	.....	+17 I.S.
4973.11.....	4 ?	1.003	.....	+18
4978.61.....	unaffected		.....	+18
4982.52.....	3 ?	1.890	.....	+26
4983.27.....	3	2.362	.....	+20
4985.27.....	3	2.337	.....	+16
4985.56.....	6 ?	2.885	.....	+19
4991.29.....	3 ?	2.023	.....	+30
5001.88.....	3	1.660	.....	+23
5005.73.....	3	1.953	.....	+32
5006.13.....	6 ?	1.176	0.724	+16
5014.96.....	4 ?	1.488	.....	+22
5022.25.....	3	1.043	.....	+24
5027.14.....	3 ?	1.998	.....	+14
5039.27.....	3	2.363	.....	+26
5090.79.....	6 ?	.....	.....	+10
5099.05 ?.....	.....	.....	.....	+20
5125.14.....	6 ?	1.976	.....	+20
5137.39.....	6 ?	2.148	.....	+14
5139.27.....	3 ?	2.713	.....	+21
5139.48.....	4 ?	2.622	.....	+20
5162.32.....	3 ?	2.200	.....	+30
5191.47.....	7 ?	2.606	.....	+19
5192.36.....	7 ?	2.780	0.790	+19 I.S.
5208.61.....	3 ?	2.294	.....	+20
5215.20.....	3 ?	2.296	.....	+20
5217.41.....	3 ?	2.259	.....	+16
5229.86.....	3 ?	2.248	.....	+15

TABLE I—*Continued*

Wave-Length	Type	n	p	Pole-Effect
5232.96.....	7 ?	1.851	.....	+25 I.S.
5263.32.....	3	2.352	.....	+20
5266.57.....	7 or 9	1.810	.....	+17 I.S.
5273.18.....	3	2.343	.....	+14
5281.80.....	?	1.115	.....	+19
5283.64.....	3	2.232	.....	+18
5302.32.....	3	2.272	.....	+14 I.S.
5324.19.....	3	2.286	.....	+15 I.S.
5339.94.....	3	2.329	.....	+19
5353.38.....	3	.....	.....	+14
5393.19.....	3	2.314	.....	+17
5473.91.....	3	2.289	.....	+14
5476.58.....	3	2.157	.....	+19
5487.78.....	4 ?	.....	.....	+36
5563.61.....	3	2.107	.....	+21
5569.63.....	7 ?	1.080	.....	+20 I.S.
5572.86.....	7 ?	1.511	.....	+25
5576.10.....	unaffected		.....	+21
5386.77.....	7 ?	1.634	.....	+24 I.S.
5602.96.....	5	1.139	2.318	+19
5615.66.....	3	1.859	.....	+22 I.S.
5624.56.....	6 ?	2.098	1.520	+23
5638.28.....	6 ?	.....	.....	+15

with the magnetic separations seems to have been but little noticed. Gale and Adams[1] remark that there is some relation between pressure-shift and magnetic separation for iron, when lines of the same group and of the same type of separation are compared. As pressure-shift is directly connected with pole-effect, the relation between the pole-effect and magnetic separation may be considered as a consequence of the fact noticed by Gale and Adams. In comparing the magnetic separation of iron lines made by A. S. King,[2] we at once notice that the pole-effect has some intimate connection with it. The lines of iron examined by King for the Zeeman effect and by St. John and Babcock for pole-effect are not always the same, so that a complete comparison is impossible, but there are many lines common to these investigations, which shed some light on the connection between the two.

Tables I and II give the wave-length, the types of magnetic separation, the amount of magnetic separation of the normal component as given by King, and the displacement of the lines from

[1] *Astrophysical Journal*, **35**, 10, 1912.

[2] *Papers of the Mt. Wilson Solar Observatory*, **2**, Part I, 1912.

the negative pole compared with the center of the arc measured in thousandths of an angstrom, taken from St. John and Babcock's[1] paper.

From the tables we notice that the types of magnetic separation are uncertain for many lines with pole-effect. There is a group of such lines extending from λ 440$_{m\mu}$ to λ 523$_{m\mu}$ showing a positive pole-effect; nearly all the lines in this interval given in the table are of doubtful types. With the negative effect, this is more strongly marked. In the latter case, the connection between the amount of separation and the pole-effect is more definite than in the former. When the mean normal separation is plotted against the negative pole-effect, the mean position of the points is nearly represented by a straight line, which is shown in Figure 1.

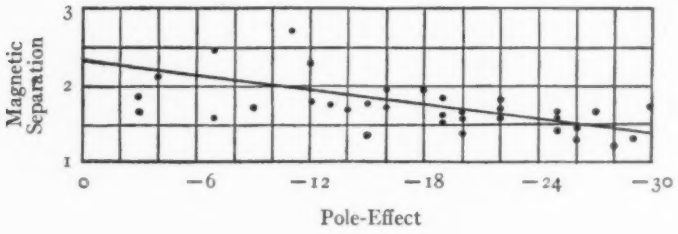


FIG. 1

It shows that the amount of separation is not at all proportional to the pole-effect, but, on the contrary, it tends to become smaller as the pole-effect increases.

Further we notice that many lines showing large pole-effect are diffuse, and are sometimes blended or fringed. Generally speaking, the Zeeman effect is characterized by the symmetry of the separated lines, with only small exceptions. The line of symmetry is generally the line in the undisturbed position, so that even if the type of separation is not exactly known, the initial position will remain unaltered. The uncertainty may arise from the unsymmetrical reversal of the lines or the widening of the lines due to the magnetizing field. Especially will the unsymmetrical widening tend to make the separation indefinite. In

[1] *Astrophysical Journal*, **42**, 231, 1915.

addition to this, the length of the arc and the nature of the material will greatly affect the vapor-pressure and the potential-gradient at the poles, and consequently produce the pole-effect. A direct

TABLE II

Wave-Length	Type	n	p	Pole-Effect
3682.21	3	1.696		− 3
3689.90 ?	6 ?	2.739	0.712	−11
3694.00	?	2.235		
3701.08	?	1.723		− 9
3748.96	4 ?	1.708		−14
3773.69	0	unaffected		−12
3797.95 ?	3	1.809		−12
3845.26 ?	6 ?	1.582	1.332	− 7
3966.62 ?	6 ?	2.147		− 4
4172.64	3			−17
4200.92	3	2.482		− 7
4433.22	3 ?			− 6
5065.02	3 ?	1.329		−29
5074.75	6 ?	1.585		−22
5079.00	?	1.771		−13
5096.99	6 ?	1.974		−16
5133.67	6 ?	1.743		−45
5364.86	6 ?	1.229		−28
5367.46	3 ?	1.437		−25
5369.96	3 ?	1.581		−20
5383.37	3 ?	1.656		−25
5404.13	3 ?	1.599		−25
5410.90	3 ?	1.486		−26
5415.19	3 ?	1.739		−30
5424.06	3 ?	1.693		−27
5445.04	3 ?	1.399		−20
5554.88	6 ?	1.628		−19
5565.78	6 ?	1.542		−19
5693.64	3			− 7
5705.99	3 ?	1.858		−19
5816.36	?	1.306		−26
5862.35	3	1.990		−18
5914.16	4 ?	1.880		− 3
5930.18	3 ?	1.669		−20
5984.81	3	1.848		−22
5987.06	3 ?	1.740		−16
6020.18	3 ?	2.332		−12
6024.06	3	1.788		−15
6042.08	?			−12
6056.99	6 ?	1.361		−15
6078.48	3 ?	1.718		−22
6102.18	3			−10
6103.19	6 ?		1.565	−15

connection between magnetic separation and pole-effect does not seem to exist, but the lines of uncertain separation show a positive or a negative pole-effect, on account of their being either diffuse

or blended, of widening or displacing unsymmetrically under pressure. Other causes, as electrostatic effect, the potential fall at the poles, and the reversal of lines, will have some influence in producing the effect.

Considering the various changes to which the iron arc in air is susceptible, the wave-length of the iron lines may be somewhat different according to the experimental circumstances. If the accuracy sought for the comparison is of the order of a milli-angstrom, it is highly desirable to use the iron arc obtained by the cathode bombardment.

My thanks are due to Mr. T. Mishima and Mr. S. Sakurai, assistants in the Institute for Physical and Chemical Research, for assisting in the experiments and calculations.

PHYSICAL INSTITUTE
IMPERIAL UNIVERSITY, TOKYO
July 1920

THE STRUCTURE OF THE BISMUTH LINES

By H. NAGAOKA and Y. SUGIURA

ABSTRACT

Structure of the bismuth lines λλ *4722, 4308, and 4122.*—The intense light produced by bombarding bismuth with a large electronic current from a limed carbon cathode was analyzed by crossing (1) an echelon grating with a glass Lummer-Gehrcke plate and (2) the glass Lummer-Gehrcke plate with one of quartz, to eliminate ghosts. Ten photographs thus obtained are reproduced. For the line λ 4722 the five positive components found by previous observers were confirmed and in addition seven weak negative satellites were discovered, showing that the line has the same general structure as most lines of heavy metals. The principal component is probably multiple, though it has not yet been resolved. Line λ 4122 has four strong components. Line λ 4308 consists of two principal lines 0.350 A apart, each of which is a narrow doublet; in addition there are two faint satellites. The authors point out some constant frequency-differences common to the satellites of these lines and suggest that they may be interpreted in terms of the quantum theory.

Fluctuations of relative intensity of the parts of the central component of the Bi line λ *4722* were observed.

The structure of the bismuth line λ 4722, studied by Baeyer and Gehrcke,[1] Takamine,[2] Lunelund,[3] and Wali-Mohammad,[4] was investigated by L. Aronberg[5] with a ten-inch Michelson plane grating. He showed that the satellites found by Baeyer and Gehrcke and Takamine are nearly correct. The bismuth line was excited by cathode particles as in the experiments of Takamine, but Baeyer and Gehrcke used a bismuth arc, and they arrived at the same result; the discrepancy between the observations of Lunelund and Wali-Mohammad lay principally in the nature of the instrument, as the orders of the spectra observed with an echelon grating are ambiguous and may be interpreted in various ways. Another curious feature in the distribution of the satellites of this line was its one-sidedness. Most of the satellites hitherto investigated, and especially those of mercury lines, are on both sides

[1] *Annalen der Physik*, **20**, 285, 1906.

[2] *Proceedings of the Tokyo Mathematical and Physical Society*, **8**, February 1915.

[3] *Annalen der Physik*, **34**, 505, 1911.

[4] *Astrophysical Journal*, **9**, 189, 1914.

[5] *Ibid.*, **47**, 102, 1918.

of the principal line, so that the $\delta\lambda$'s are both positive and negative; with the bismuth line, they are confined to the positive side only. We have no doubt as to the order of the grating spectra, and the position is uniquely determined; the only objection is, however, the weakness of the spectra of higher orders, so that only with long exposures can we photograph all the satellites. Some doubts were expressed concerning Takamine's photographs, as faint traces of dots were visible in the immediate neighborhood of the positive satellites, which appeared as distinct interference points. This seemed to be due to some instrumental error, and no measurements were made on them. With the lime cathode of carbon, which we have recently developed for spectroscopic work, currents of 2.5 to 4.5 amperes could be maintained for some time between the cathode and the anode of the metal to be studied, so that it was interesting to test the singularity in the structure of the bismuth line with new and powerful means of excitation, and by using a Lummer-Gehrcke plate of glass and one of quartz, which can be crossed with each other to detect the presence of ghosts. By this means we found that the satellites are not confined to the positive side only, but there are many faint components on the negative side, so that the structure of the bismuth line is similar to most of the complex lines of other elements.

The instruments used were as follows, and were all made by Hilger:

An echelon grating of 35 plates, thickness of each plate 9.350 mm with steps of 1 mm; resolving power 435,000 for wave-length λ 5000.

A Lummer-Gehrcke plate of light flint glass; length 20 cm, thickness 1.09116 cm, resolving power 400,000.

A Lummer-Gehrcke plate of quartz; length 13 cm, thickness 4.724 mm, resolving power 566,000.

The spectra were photographed by means of a micro-planar of 7.5 cm focal length, after crossing the echelon grating and the glass plate, while those produced by crossing the plates of glass and quartz, using the extraordinary ray, were photographed with a large quartz spectrograph provided with a Cornu prism. The crossed spectra so obtained were examined with a micrometer

PLATE VIII

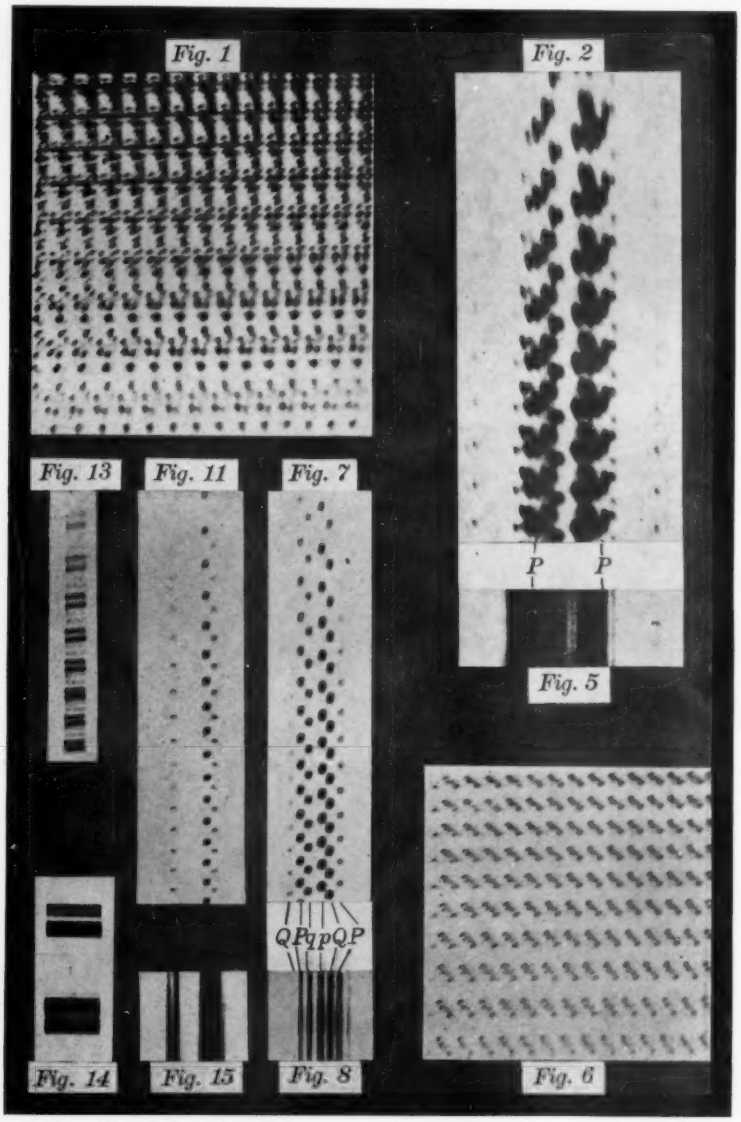


FIG. 1.—Bi λ 4722. Glass L. G. plate crossed with quartz L. G. plate
FIG. 2.—Bi λ 4722. Echelon crossed with L. G. plate
FIG. 5.—Bi λ 4722. Echelon
FIG. 6.—Bi λ 4122. Glass L. G. plate crossed with quartz L. G. plate
FIG. 7.—Bi λ 4122. Echelon crossed with glass L. G. plate
FIG. 8.—Bi λ 4122. Echelon
FIG. 11.—Bi λ 4308. Echelon crossed with glass L. G. plate
FIG. 13.—Bi λ 4308. Quartz plate
FIG. 14.—Bi λ 4308. Horizontal echelon
FIG. 15.—Bi λ 4308. Echelon

microscope and with a comparator. As we had no experience with the crossing of the quartz plate, a preliminary experiment was made on the mercury line λ 4359. The measurement of the plate showed close coincidence in the position of the satellites, as already given by one[1] of us from a combination of a Lummer-Gehrcke plate with a Fabry-Perot interferometer.

Structure of the line λ 4722.—Crossed spectra of λ 4722, obtained by the combination of the glass and quartz plates, and by the echelon grating and the glass plate, are shown in Figures 1 and 2 (Plate VIII). The former shows at once a number of components which are more numerous than those hitherto given, while the

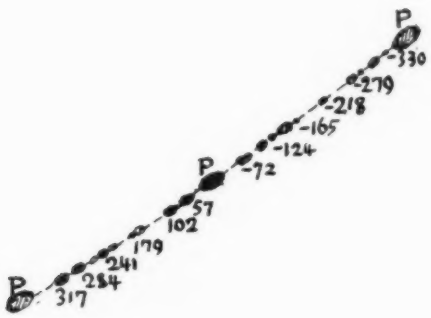


FIG. 3.—Quartz and glass plates

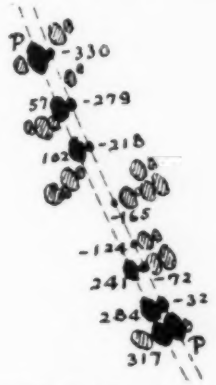


FIG. 4.—Glass plate and echelon

latter is almost similar to the photograph obtained by Takamine, but is marked by a number of weak interference points, very near to those whose position has been already determined by previous investigators. These weak points evidently correspond to spectra of higher order; by following the line connecting them, they are found to belong to the negative components. The existence of false lines due to certain instrumental errors, such as reflection within the echelon plates, may be suspected, but comparison with the crossed spectra of the Lummer-Gehrcke plates will at once decide the question whether or not the doubtful wave-lengths are real. On studying the points, we found that they are arranged according to the following scheme (Figs. 3 and 4). The negative

[1] *Proceedings of the London Physical Society*, **29**, 91, 1917.

components are very faint and the exact position rather difficult to make out; consequently the error of setting during the measurements is not small, and the coincidence in the position of the lines is not perfect, as with the positive components.

TABLE I

Crossed Spectra		Crossed Spectra		Mean	Intensity
Glass Plate	Quartz Plate	Glass Plate	Echelon		
0.316 A	0.314 A	0.320 A	0.318 A	0.317 A	7
281	282	285	287	284	7
241	238	243	243	243	8
179	179	?	?	179 ?	1
102	101	103	102	102	6
56	58	56	58	57	8
0	0	0	0	0	10
faint	faint	− 31	− 32	− 32	1
faint	68	− 76	− 78	− 72	1
− 122	− 124	− 109 ?	− 126	− 124	0.5
− 167	− 168	− 155	− 169	− 165	0.5
− 219	− 219	− 218	− 216	− 218	3
− 295 d*	− 293 d	− 263	− 265	− 279	1
−0.328 d	−0.330 d	−0.322	−0.321	−0.328	1

* d = diffuse

TABLE II

Gehrcke and Baeyer	Takamine	Aronberg	Nagaoka and Sugiura
0.316 A	0.320 A	0.318 A	0.317 A
289	284	284	284
242	238	240	243
104	102	102	102
57	56	56	57
0	0	0	0
.....	.....	.....	− 32
.....	.....	.....	− 72
.....	.....	.....	− 124
.....	.....	.....	− 165
.....	.....	.....	− 218
.....	.....	.....	− 279
.....	.....	.....	−0.328

Further comparison with the echelon spectrum alone was made, but as several components on the positive and the negative side were found to be nearly coincident, as shown in Figure 5 (Plate VIII), the question was difficult to settle with this photograph. The table gives the position of the satellites with reference to the principal line.

The coincidence between different instruments is nearly perfect for the positive components, but with weak negative components the discrepancy is tolerably large. It is certain that with intense light we can observe components on the violet side of the principal line, which lie nearly in the middle of the numerous satellites. This is the general characteristic of most complex lines, and the bismuth line λ 4722 presents no singularity, which the old determinations seemed to indicate.

It must, however, be noticed that there is a zinc line at λ 4722.164 in the neighborhood of the bismuth line. The line is apparently double or triple but, if bismuth contains zinc as an impurity, the components of the line may appear as satellites and give false structure to the bismuth line. Crossed spectra of a mixture and zinc were taken, showing that the zinc line is not in line with bismuth on the drawing, Figure 3, and can be easily eliminated. In the crossed spectra of bismuth given in Figures 1 and 2, there is no indication of the presence of zinc.

Another probability is the intrusion of the line λ 4733 belonging to bismuth into the crossed spectra of λ 4722. By placing the edge of the echelon horizontally, the position of the line relative to λ 4722 in the spectra was ascertained. It was evident that the line may appear as satellite +180 or −328; consequently there is some doubt as to whether or not the component +179 may be due to intrusion. This line was therefore eliminated from the table.

The blue line of bismuth thus consists of more than a dozen components and resembles the green line of mercury, λ 5461. It is perhaps characteristic of such heavy elements that they have a large number of lines with complex structure. The lines of bismuth, lead, and mercury, including the band spectra, seem to be of this nature.

Structure of the line λ 4122.—The bismuth line λ 4122 was studied by Kayser and Runge, Gehrcke and Baeyer, Lunelund, and Takamine. The first-mentioned physicists give the line as a doublet, the second as a triplet, the third and fourth as a quartet, but the intervals are all different.

To settle this point, crossed spectra were taken as shown in Figures 6 and 7. The interpretation of the spectra is graphically

represented in Figures 9 and 10. The principal lines are denoted by P and Q in the figures, the interval between them being 0.200 A; they are accompanied by two lines on the positive and the negative side as given in the table. Taking P as the principal line, we have the following lines.

TABLE III

	Crossed Spectra		Crossed Spectra		Mean	Intensity
	Glass Plate	Quartz Plate	Glass Plate	Echelon		
p.....	0.123 A	0.124 A	0.121 A	0.120 A	0.122 A	8
P.....	0	0	0	0	0	10
Q.....	− .201	− .199	− .202	− .198	− .200	10
q.....	−0.321	−0.321	−0.323	−0.317	−0.321	8

The next table gives the comparison of different determinations.

TABLE IV

Gehrcke and Baeyer	Takamine	Lunelund	Kayser and Runge	Nagaoka and Sugiura
0.150	57	0.050	.....	0.122
0	4122.010	0	4122.010	0
−0.210	4121.690	− .050	4121.690	− .200
.....	− 58	−0.110	.....	−0.321

Evidently Kayser and Runge took the mean points of the first two and of the last two lines as a doublet, whose interval is 0.32 A. In the interpretation of the crossed spectra Takamine seems to have

FIG. 9.—Echelon and glass plate

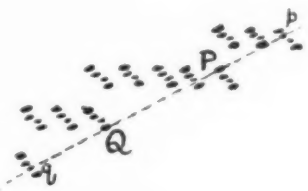


FIG. 10.—Glass and quartz plates

been misled by Kayser and Runge's value, which clearly had the above meaning, and did not refer to the interval between the doublets. It is thus seen how the results obtained with one or

two interferometers are sometimes erroneous; possibly three such instruments will be necessary to solve the problem of the distribution of the satellites without ambiguity.

Structure of the line λ *4308.*—The bismuth line λ 4308 was examined with the crossed spectra of an echelon grating and a Lummer-Gehrcke plate as shown in Figure 11, but the details are not clearly made out; it will perhaps require a higher voltage to obtain good results. The principal lines form a doublet at distance of 0.350 A, and each line is a doublet at intervals of 0.024 and 0.023 A. They are accompanied by two faint satellites 0.117 and −0.106, from mean points of the doublet forming the principal lines as shown in Figure 12. The existence of the faint

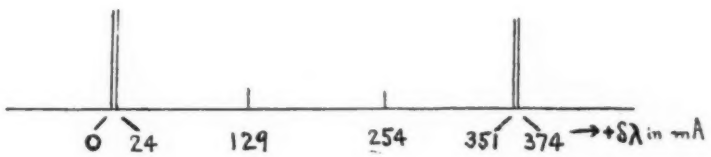


FIG. 12.—Structure of λ 4308

satellites is clear from the photograph obtained with the quartz plate, shown in Figure 13. The results obtained with the echelon grating (Figs. 14 and 15), glass and quartz plates agree tolerably well with each other. This line had not been investigated by other physicists, so that we have no other data with which to compare the measurements.

Regularity in the frequency intervals.—As one of us has already noticed, we sometimes meet with a constant difference in the frequency of the satellites. Such was found to be the case with the mercury and cadmium lines; the bismuth lines seem to show the same characteristic, which is evident in Table V, which illustrates the difference in wave-numbers $\delta\nu = -\frac{\delta\lambda}{\lambda^2}$ per cm. It is to be remarked that the differences found on page 346, Δ_1, Δ_2, Δ_3, are nearly in the ratio 5:3:2. In addition to this, some of the differences are multiples of other differences, as may be seen from the tables.

TABLE V

λ	$\delta\nu \times 10^4$	λ	$\delta\nu \times 10^4$
(A) 4122	188.5	(C) 4722	−142.2
	117.6		−127.3
	− 71.8		− 80.3
			− 45.8
(B) 4308	− 63.1		− 25.6
	+ 57.1		0
	± 12.7		14.4
			32.3
			55.6
			74.0
			97.8
			125.0
			147.0

From these we find:

A: 117.6− 0=117.6
B: 188.5−71.8=116.7
63.1+57.1=120.2
C: 142.2−25.6=116.6
147.0−32.3=114.7

Mean=117.1=Δ_1

A: 117.6−71.8=45.8
B: 57.1−12.7=44.4
45.8− 0=45.8
C: 127.3−80.3=47.0
97.8−55.6=42.2

Mean= 5.0=Δ_3

25.6 (C)=2×12.8 (B)
188.5 (B)=3×62.8 (B)
127.1 (C)=3×42.4=3Δ_3
71.8 (A)=5×14.4 (C)
63.1 (B)=5×12.6 (B)

A: 71.8− 0=71.8
B: 63.1+12.7=75.8
C: 147.0−74.0=73.0
125.0−55.6=69.4
74.0− 0=74.0
45.8+25.6=71.4

Mean=72.6=Δ_2

147.0 (C)=2×73.5
142.2 (C)=2×71.1

Mean 144.6 =2×72.3=2Δ_2

127.3 (C)=2×63.6
125.0 (C)=2×62.5

Mean 126.1 =2×63.1 (B)

The interpretation of the foregoing results will probably rest on quantum relations, having some connection with the electronic configuration of the atom.

With heavy elements, it is clear that the number of bound electrons about the atomic nucleus is numerous, so that the electronic configuration is not unique, but there are a great number

of stable distributions of electrons which differ slightly from one another. If the emission of light takes place by the passage of electrons from one configuration to another, the difference in frequency in a slightly varied system will be small, if the initial or the final system be but little different from the system giving rise to the principal line; thus the existence of satellites can be easily explained.

Consider that the emission of frequency ν takes place according to Bohr's scheme

$$h\nu = W_1 - W_2$$

where h is Planck's constant and W_1 and W_2 are the initial and final energy of the electron; then

$$h(\nu+\delta\nu) = W_1 - W_2 + \delta W,$$

where δW may be due either to the change in the initial or final configuration of the electrons, or in both configurations. If δW remains constant in the altered system, and the initial orbit of the radiating electron remains unchanged, it is possible to have different lines with constant difference in frequency. Thus the regularity in the frequency differences is probably to be ascribed to the small variation in the initial or final configuration of the radiating electrons.

In the experiments here described, the lines were excited by swiftly moving cathode particles; the voltage was perhaps insufficient to bring out minute details of the component satellites; but we believe that the details of λλ 4722 and 4122 were cleared up in the present experiment by using a higher voltage and a greater current-density between the electrodes than were used by previous investigators. A lime cathode of carbon can be used with advantage in such spectroscopic work, and the cost of such cathodes is negligible compared with the limed platinum cathodes, which wear out after some use.

An important observation was made by one of us during the experiment with the echelon spectrum of λ 4722. The principal line had finite breadth, and the intensity was somewhat fluctuating. It was first thought that the whole line would be subject to such

alternations of intensity, but actual observation showed that only a small portion of the line was subject to flickering, from which it appeared that what was supposed to be a single line consists of three or four lines closely packed together, as is the case with the green line of mercury, λ 5461. It is somewhat singular that all parts of the line are not simultaneously affected. Perhaps such fluctuations are caused by the minute change in the electronic configuration within the atom, and the light is excited by the intrusion of high-speed electrons from the cathode into the atomic system. The electron groups giving rise to the visible spectrum are confined to the outside boundary of the atom, and the configuration will be more susceptible to small changes than in the neighborhood of the atomic nucleus, where X-ray spectra are excited. If we can obtain some means of supplying electrons of moderate speed, we shall ultimately obtain some easy means of powerful illumination.

In conclusion, we have to thank Mr. T. Mishima and Mr. S. Sakurai, assistants in the Institute for Physical and Chemical Research, for great help rendered during the experiment and in the reduction of the results.

PHYSICAL INSTITUTE
IMPERIAL UNIVERSITY, TOKYO
August 1920

THE MUTUAL ACTION OF ADJACENT PHOTOGRAPHIC IMAGES[1]

By FRANK E. ROSS

ABSTRACT

Mutual action of adjacent photographic images.—(1) *Stars and bright lines.* A review of previous work shows that the results are so conflicting that general conclusions cannot be drawn. Three factors seem to control the action. The *turbidity effect* causes an attraction through optical reinforcement of adjacent sides of the images. An equation is derived from which the attraction is found to be negligible, except for very small images very close together. The *gelatine effect* causes an attraction due to the more rapid drying of the developed image. It is measured by the difference in the separation of images when wet and when dry. For normal exposures of star images less than 0.1 mm apart the attraction is equal to about 2 μ for ordinary developers excepting pyro-metol, while in the case of lines the attraction is about 5 μ. This attraction is only slightly changed by varying the amount of sulphite or by the use of a hardener. The *developer or Kostinsky effect* causes a repulsion as a result of the restraining effect of the products of the developing reaction, as in the Eberhard effect. It varies somewhat with the developer but increases with the exposure. The *variation of the total effect with exposure* is such that overexposed images show strong repulsion due to the large developer effect, whereas normally exposed images show an attraction which usually amounts to 2 or 3 μ. To minimize the error which the effect may introduce into measurements of such images, the exposure should be as short as possible. The phenomenon is so complicated that it may be impossible to eliminate it completely. (2) In the case of *absorption lines*, both the gelatine effect and the developer effect cause a repulsion, but in addition to the attraction due to the turbidity effect there is a further attraction due to a difference in the sharpness of outer and inner edges caused by turbidity and halation. In general the total effect is an attraction, about 1 μ for normal exposures but larger for overexposures. Seed 30 plates were used.

Effect of exposure on the time of drying of photographic film.—A normally exposed image dries faster than an underexposed or an overexposed region.

On account of the high degree of precision which had been reached in the determination of the positions of the stars by photography during the first decade of its application to this field, it was not unnatural to suppose that the photographic method could be employed with equal advantage in the determination of the relative positions of double stars and satellites. In both of these special fields of observational astronomy, the systematic errors in the usual visual methods are both troublesome and

[1] *Communication from the Research Laboratory of the Eastman Kodak Company*, No. 119.

important, so that it was hoped that photographic methods might be employed with profit. However, without any question being raised at the time as to the accuracy of the photographic results, it was at once found that its application to the measurement of double stars was limited to pairs of only moderate separation, the important pairs having a separation of the order of one second of arc or less being unresolvable even with the largest telescopes. A greater field of usefulness appeared in observations of satellites, in which it is important to eliminate the systematic errors known to be present in the visual observations.

The first to question the accuracy of photographic measures of double stars and satellites, as far as the writer is aware, was S. Kostinsky[1] in 1906. He observed an apparent repulsion of neighboring images and cites as a possible explanation the well-known fact that in the wet condition images lie below the surface of the surrounding gelatine. In a later paper[2] Kostinsky discusses the phenomenon at length. By photographing a wide double star for varying exposure times, he finds a progressive retrocession of centers, as the following data, taken from his measures, show:

Exposure Time	Diameter		Distance between Borders	Measured Distance between Centers
	Star	Companion		
min.	mm	mm	mm	mm
1.....	0.282	0.039	+0.086	0.2467
16.....	0.482	0.080	−0.014	0.2667

Thus for the long exposure, giving an overlap of 0.014 mm, the distance relative to that for the shorter exposure increases 0.020 mm. From all data he finds the contraction of centers, y, in microns:

$$y = 7.9\left(1 - e^{\frac{80-x}{100}}\right)$$

where x is the distance in microns between adjacent borders of the images of the stars.

[1] *Mittheilungen der Nikolai-hauptsternwarte zu Pulkowo*, Vol. I, No. 11.

[2] *Ibid.*, Vol. II, No. 14.

H. E. Lau[1] in 1912 obtained similar results from a different procedure. He exposed a plate to the Praesepe cluster for five minutes, then moved the telescope about 11″ and exposed again for five minutes. A series of double stars of equal components but of a wide range in magnitude is thus obtained, which should vary in separation if the Kostinsky effect is present. The resulting repulsion, y, as a function of the distance between borders, Δ, is shown in the following table:

Δ mm	y mm
0.034	0.0027
.051	.0019
.069	.0008
.086	.0001
.103	.0000
.120	.0000
0.138	0.0000

Kostinsky's formula gives for $\Delta = 0.034$, a contraction $y = 0.0046$ mm, which is somewhat larger than Lau's value.

H. H. Turner,[2] on the other hand, notes an apparent *attraction* between adjacent lines on a photographic plate, *réseau* lines intersecting at a small inclination being bowed inward near the point of intersection. The effect vanished when the centers of the lines were separated by $\frac{1}{3}$ mm or more. When the lines were in contact, the centers being then separated by 0.075 mm (computed), the actual separation was less by 0.006 mm. This means that two fine spectral lines, each of width 0.075 mm, and in contact, have had their true separation diminished by 8 per cent. Turner attributed the phenomenon to a displacement of the light maxima in the images, a phenomenon discussed at length below.

F. A. Bellamy,[3] from a study of the double stars of the Oxford astrographic catalogue, supports Turner's conclusions. Bellamy compares the photographic separations with the values in Burnham's *General Catalogue*. In all, 436 pairs were examined. In the case of the overlapping images (overlapping one-third of the radius) the apparent contraction was large, averaging about 8 per

[1] *Astronomische Nachrichten*, **192**, 179, 1912.

[2] *Monthly Notices*, **77**, 519, 1917.

[3] *Ibid.*, **77**, 521, 1917.

cent. With images not quite in contact, the clear space being 0.02 mm, the contraction amounted to 2 per cent. When the clear space became about 0.08 mm all trace of contraction disappeared.

Hertzsprung[1] finds both contraction and repulsion in photographic measures of double stars depending on the atmospheric conditions and on the separation of the components. He explains the attraction as arising from the addition of density to each image at its inner edge, due mutually to the light from the other. This explanation is the same as Turner has suggested. He finds the effect most pronounced on nights of bad seeing, amounting to 0.007 mm. On the other hand, repulsions occur on nights of the best definition and in the case of close pairs.

Mitchell and Olivier[2] made an extended series of photographic measurements of the triple star Krueger 60, in which the components A and B approached within 1".84 (0.09 mm) of each other. Comparison with Barnard's visual measures shows no evidence of either attraction or repulsion.

There appears to be but little in the literature on the behavior of close spectral lines. C. E. St. John[3] has the following:

> A comparison has recently been made between the separation of close pairs as given in the Rowland tables and as measured upon plates of higher dispersion than that used by Rowland. For pairs consisting of lines of intensities 3 and 4 whose separations are 0.0 to 0.1 Å, 0.1–0.2, and 0.2–0.35, the Rowland values exceed those found at Mt. Wilson by 0.011 Å, 0.007 Å, and 0.004 Å, respectively.

From one point of view these can be considered as repulsions of the lines on the Rowland plates, the scale of which is 1 Å = 1 mm. The effect appears to be greater and effective at greater separations than found in the case of stellar images described above. However, according to another investigation by St. John,[4] there is evidence of part of the effect at least being due to psychological causes. He finds that for measures of close spectral lines made in the ordinary way and on the Koch microphotometer, the microphotometer gives the smaller separation.

[1] *Observatory*, **44**, 56, 1921. [2] *Astronomical Journal*, **32**, 179, 1920.

[3] *Proceedings National Academy of Sciences*, **2**, 228, 1916.

[4] *Year-Book of the Carnegie Institution of Washington*, No. 15, p. 240, 1916.

On the other hand, F. Goos[1] finds that Kayser's measures of the separation of close doubles in the iron arc differ from his own in the following way:

Average separation, 0.24 Å = 0.09 mm,
Separation (Goos − Kayser), −0.0042 Å = −0.0016 mm ± 0.0004 mm,
Scale: Kayser, 1 Å = 1 mm; Goos, 1 Å = 0.36 mm.

Since the scale of Kayser's plates is the greater, these results show that the lines of Goos's plates suffer an *attraction* in opposition to the repulsion shown on the Rowland plates. Thus an inconsistency in the results affecting any general conclusions is to be found in measures of spectral doubles, as well as in measures of double stars.

The writer has previously investigated the action of adjacent images on each other in the particular case of a large central image and a small neighboring image.[2] The smallest distance between adjacent borders utilized was 0.12 mm, in which case under certain conditions of development the small image was displaced toward the larger by 0.020 mm. The effect was found to be appreciable when the border separation became as great as 0.42 mm, the image displacement in this case being 0.006 mm. The effects are thus seen to be larger and operative at greater distances than in the cases noted by the writers quoted above. They agree in general with the results of Turner, Bellamy, and Goos in showing the existence of a contraction, and are apparently opposed to those of the earlier investigators and to St. John's results.

Aside from possible systematic errors of measurement, there appear to be three distinct factors controlling the deviations from normal action in the case of neighboring images, as follows:

a) A mutual light-action causing each of the images to assume an oval form, the geometrical centers being displaced inward, the result being an apparent attraction. This effect will be called the "turbidity effect."

b) Displacements of the gelatine in which the images are imbedded, which can be called the gelatine effect, measured and discussed by the writer in the paper quoted.

c) It appears necessary to assume the existence of an abnormal action of the developer in developing the latent image, such as is

[1] *Astrophysical Journal*, **35**, 232, 1912. [2] *Ibid.*, **52**, 101, 1920.

found in the Eberhard effect.[1] One of the main objects of the present paper is the investigation of this effect, which may be called the "Kostinsky effect." Each of the three phenomena will be considered at some length.

The turbidity effect.—Consider the case of photographing a double star or a pair of spectral lines having components of equal intensity. The distribution of light in the film due to each component is[2]

$$I = I_0 e^{-\kappa r}, \tag{1}$$

where I_0 is the intensity in the central diffraction disk, and I the intensity at a distance r from the center of star or line. κ is a parameter whose numerical value is given by

$$\kappa = \frac{2 \log 2}{\text{Mod.}} \times \frac{1}{m} = \frac{1.386}{m}, \tag{2}$$

where m is the increase, in microns, in the diameter of one of the stellar images or spectral lines for each doubling of the exposure time, or, more strictly, for doubling of the intensity. The relative distribution of light is thus fully determined.

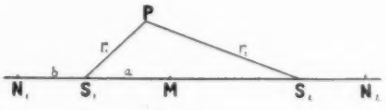


FIG. 1

Let S_1 and S_2 (Fig. 1) represent the centers of a pair of close stars of equal components. Let P be any point in the immediate neighborhood, distant r_1 and r_2 from S_1 and S_2. The total intensity of light at P is evidently

$$I_P = I(e^{-\kappa r_1} + e^{-\kappa r_2}). \tag{3}$$

The boundary line of the stellar image is determinable by the condition $I_P = \text{constant}$, which gives as the equation of its outline

$$e^{-\kappa r_1} + e^{-\kappa r_2} = \text{constant} = C. \tag{4}$$

[1] *Physikalische Zeitschrift*, **13**, 288, 1912.

[2] *Astrophysical Journal*, **52**, 206, 1920.

This represents a family of transcendental curves, real branches of which are a family of lemniscates. In Figure 2 a number of the curves are accurately drawn to scale. The practical case is chosen of a separation of centers of 0.1 mm. κ is chosen equal to 0.05, corresponding to $m = 28$, a value which is of the order of magnitude found for large telescopes and high-speed emulsions. In Figure 2 a pair of point images are chosen, corresponding to the case of critical definition. In Figure 3 the curves for disk-images are shown. In this case r_1 and r_2 are measured from the edge of each

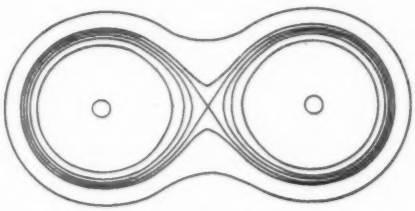


FIG. 2.—Outlines of neighboring images for point sources

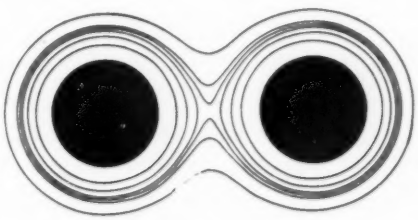


FIG. 3.—Outlines of neighboring images for equal circular sources

disk. It is seen that the character of the curves is the same in the two cases. The curves are oval in form, becoming more and more pronounced as the exposure time or intensity is increased. The center of each image is displaced toward the other, the amount of the displacement increasing with the size. In other words, double stars and close spectral lines are subject to an apparent *attraction* of an amount depending upon the separation of their adjacent borders. In the important and interesting case of *contact* the figures show that instead of the images coming together along a curve as would naturally be expected, they meet in a point, the outline of each image in the neighborhood of their intersection being

composed of two lines intersecting at an angle of considerable size in the practical cases under consideration. These oval forms should be observable, and the corresponding attraction of centers should be measurable. That they are not, in general, is due to the masking effect of the Kostinsky phenomenon, as will appear later.

It is not difficult to obtain a formula giving the attraction or displacement of centers of adjacent stellar images or spectral lines. Since the maximum effect is attained for equal components, only that case will be considered. The method is easily extended to the case of unequal components. Referring to Figure 1, putting $S_1S_2=s$, equating the illumination at M with that at N,

$$I[e^{-\kappa a}-e^{-\kappa(s-a)}]=I[e^{-\kappa b}+e^{-\kappa(s+b)}]\,. \tag{5}$$

In all practical cases the second term on the right can be neglected. The equation is then rearranged as follows:

$$e^{\kappa(a-b)}=1+e^{-\kappa(s-2a)}\,. \tag{6}$$

Put

$\delta=$ total displacement of centers,

$r=$ separation of adjacent edges;

it is evident that

$$\delta=a-b,$$
$$r=s-2a,$$

leading to the following simple equation for the "attraction" of double stars or spectral pairs

$$e^{\kappa\delta}=1+e^{-\kappa r}\,. \tag{7}$$

For the special case of contact of images, the equation becomes

$$e^{\kappa\delta}=2,$$

or finally, since

$$\kappa=\frac{2\log 2}{\text{Mod.}}\frac{1}{m},$$

$$\delta=\tfrac{1}{2}m; \tag{8}$$

hence we have the remarkable theorem that in the case of contact of images the contraction is equal to the increase which takes place

in the radius of a stellar image for each doubling of the exposure time, and is moreover independent of the size of the image itself. The theorem applies to spectral lines as well, in this case the radius being replaced by the half-width. In practical cases m lies between 10 (very sharp) and 30 (diffuse); the corresponding maximum attraction of stellar images or spectral lines accordingly lies between 0.005 mm and 0.015 mm. Table I, computed from (7), gives the value of the attraction δ for various values of m, and of r, the separation of the adjacent edges of stellar images or spectral lines.

TABLE I

VALUES OF δ (IN MICRONS)

m	10μ	15μ	20μ	25μ	30μ
κ.....	0.139	0.093	0.070	0.056	0.046
mm					
r=0.000.....	5.0	7.5	10.0	12.5	15.0
.010.....	1.6	3.6	5.8	8.1	10.6
.020.....	0.4	1.6	3.2	5.0	7.3
.040.....	0.0	0.3	0.9	1.8	3.2
0.080.....	0.0	0.0	0.1	0.2	0.5

The gelatine effect.—As already remarked, data have been collected by the writer on the mutual action of adjacent images in the case where one of the images is large. It is necessary to measure the effect in the case of small images, as in double stars and close spectral lines. The experiments must be so arranged that the effects so far as possible can be differentiated.

It has been shown (*Astrophysical Journal*, **52**, 106, 1920) that movements of the gelatine surrounding and within adjacent images cause an apparent attraction between images which is brought into evidence by comparing measurements of the same pairs made with plate wet and plate dry. It is clear that this effect can be differentiated from the "attraction" of the latent image already discussed, and from the "repulsion" of the Kostinsky effect discussed in a later paragraph.

A test-object, A, composed of ten artificial double stars, all of equal size, was photographed on Seed 30 plates, the separations being adjusted so as to reproduce conditions obtaining in practice. It was photographed in a special precision camera reducing 20

diameters. An enlargement of one of these exposures is shown in Figure 4. The separation of the close pair (jj') is 0.052 mm, and of the widest pair (aa') 0.104 mm. The average diameter of the images is 0.04 mm. Five exposures were made on each plate

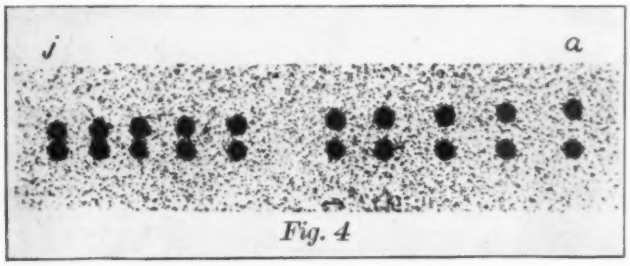


FIG. 4.—Enlarged images of double-star test object

and were measured wet and dry. The plates, ten in all, were developed in several different kinds of developer, including the staining: pyro, pyro-metol, and caustic hydroquinone; and the non-staining: hydroquinone and metol-hydroquinone. Since the differences brought out between the action of the various developers,

TABLE II

CONTRACTION IN DRYING OF IMAGES OF CLOSE DOUBLE STARS (IN MICRONS)

Pair	Mean of Ordinary Developers	Pyro-Metol	Edge Separation
	μ	μ	mm
aa'	0.9	8.4	0.080
bb'	1.4	5.6	.071
cc'	1.4	7.0	0.62
dd'	1.8	5.0	.053
ee'	1.8	5.2	0.44
ff'	2.0	3.4	.036
gg'	2.0	5.6	.027
hh'	2.3	.....	.018
ii'	1.2	.....	.009
jj'	0.9	.....	0.000±
Mean	1.6	5.7	

excepting the single case of pyro-metol, were not striking, the results from all ten plates are averaged in Table II. All measurements recorded in this and in the following tables were made on a

Hilger comparator at a uniform magnification of 75. The plates in all cases were Seed 30.

The values for the pairs *i* and *j* are uncertain owing to the difficulty of accurately measuring pairs in close contact. For this reason the last three pairs were not measured on the plate developed in pyro-metol. It is seen that the very strongly staining and tanning developer, pyro-metol, stands apart from the ordinary developers in the magnitude of the contraction, confirming the results found and described in a former paper.[1] A further conclusion of importance is that the contraction is *independent* of the separation, within the limits of the experiment, which include all practical cases of interest. It can be concluded that, for the close doubles of separation 0.1 mm or less, the contraction due to the movement of the gelatine is 0.0016 mm for all ordinary developers. That different results were not obtained for the two classes of developers, staining and non-staining (with the single exception of pyro-metol), seems surprising in view of the results obtained previously. In the previous work, however, a much larger test-object was used, so that the conditions of the experiments were not similar to those just described. It is clear that much work remains to be done on this branch of the subject before general conclusions as to the action of different developers can be reached.

The series of measurements on the double-star group furnishes information on the Kostinsky effect, as well as on the gelatine effect just considered, for measurement of the separation of the double stars on the test-plate itself, assuming no distortion in the optical system, gives the relative values of the separation of the images of the test-plate. For this comparison only the pairs *aa'* and *jj'* will be considered. The results are:

	mm
Separation of centers of *aa'* in test-plate	2.000
Separation of centers of *jj'* in test-plate	1.022
Photographed *aa'* (measured wet)	0.1049
Photographed *jj'* (measured wet)	0.0532

By simple proportion from the first three quantities, *jj'* should be 0.0536 mm. This agrees with the measured value within the

[1] *Astrophysical Journal*, **52**, 101, 1920.

error of measurement, leading to the conclusion that no distortion of any kind is apparent. But from Table I, assuming $m = 10$, a value close to the true one, and assuming further that the images j and j' are in contact, we find a computed turbidity contraction of 0.0050 mm. Since the gelatine effect has already been eliminated, it must be concluded that in this case the turbidity contraction and the Kostinsky repulsion are mutually destructive. This is not surprising since attractions and repulsions in equal number have been obtained by various investigators, as shown in the introduction.

The gelatine effect for spectral emission lines.—The test-object, B, in this case consisted of two pairs of parallel lines having equal components, which were photographed on Seed 30 plates in the same way as the double-star test-object. The pairs are designated *a* and *b* in Table III, which gives the results of measurement.

TABLE III

CONTRACTION OF SPECTRAL PAIRS IN DRYING

	a	*b*
Mean separation (dry)	0.149 mm	0.107 mm
Mean width of lines	0.100 mm	0.080 mm
Contraction with caustic-hydroquinone dev	5.0 μ	4.3 μ
Contraction with chlor-hydroquinone dev.	4.6 μ	4.6 μ
Contraction with pyro-soda dev	6.2 μ	6.0 μ
Contraction with pyro-metol dev	15.4 μ	14.3 μ

It is seen that the gelatine contraction for spectral pairs is twice that for double stars of equal separation. This may be in part due to the greater width of the spectral lines, as well as to their linear extent. Further experiments with narrower lines are to be made. It appears to be true that the gelatine effect is greater for the important case of spectral doubles than in that of double stars. As in the case of double stars (Table II), all developers excepting pyro-metol are seen to give nearly the same effect.

Effect of sulphite.—Since the staining and tanning action of a developer to a certain extent can be controlled by its sulphite concentration, corresponding variations in the contraction of the gelatine should occur if it is true that tanning of the gelatine is

a factor in contraction of the image. Experiments were made with pyro developer in which the amount of sulphite was altered between wide limits. It is not necessary to give details. The contraction was actually found to diminish with increasing sulphite.

Action of hardening agents.—It is found that hardener in the fixing bath reduces the contraction only slightly. In a different experiment, plates after fixing were bathed in a concentrated solution of quinone; and in another case in a 10 per cent formalin solution. In order to obtain the maximum effect, the plates were developed in pyro-metol. An average reduction of 25 per cent in the contraction was obtained. These results were expected, since hardening of the gelatine should not alter to any great extent the variation of water content of a developed image with its density.

Drying time of a developed image.—It is desirable to have direct or observational data on the drying time of a developed image, since in the explanation given by the writer of the contraction of

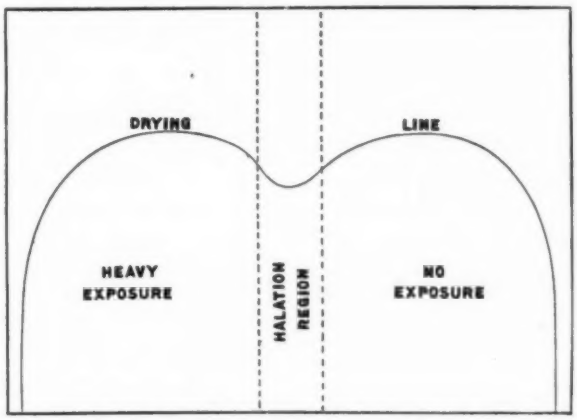


FIG. 5.—Drying line on a partially dried plate

an image due to movements of the gelatine it is assumed that a developed image dries more quickly than the clear gelatine surrounding it. The following experiments were made.

Five-by-seven plates were exposed to light over half their surface, developed in pyro-metol, and after fixing allowed to dry. The exposed portion was found to dry more quickly in all cases. Figure 5 shows the drying line of a partially dried plate, one-half

of which had been subjected to a heavy overexposure. Between the region of overexposure and the clear gelatine there is a halation strip one inch in width. The dip in the drying line in the halation region brings out the remarkable fact that a normal exposure dries more quickly than either clear gelatine or an overexposure. This difference in drying between normal and overexposure was verified by numerous experiments.

The Kostinsky effect.—The anomalous actions just discussed which affect the true distance between images of close double stars and spectral lines on a photographic plate are not competent to explain the phenomena actually observed, for, as shown, both the turbidity effect and the gelatine effect result in an apparent attraction of images. As cited in the introduction, there are many conclusive cases of apparent repulsion of images, so that we must look to a third class of anomalous actions to explain all the facts observed.

One method of studying the mutual action of adjacent images is that followed by Kostinsky, namely, of measuring the distance of centers of a series of images of a double star or close spectral pairs, real or artificial, the time of exposure being varied in such a way that the size of the images varies from threshold to one producing contact or even overlapping. When the experiment is made in this way, it must be assumed that the distribution of light in each image is perfectly symmetrical, or at least that any dissymmetry is the same for both images. However, with good modern optical instruments a lack of symmetry need not be feared, if exposures are made on close doubles and in the optical axis. In this connection it may be said that Lau's method (p. 351) of obtaining the effect is open to question on this account, since the exposures were not axial, but distributed over the plate. It is quite likely, however, that this error is negligible.

Experiments with artificial double stars.—Two pairs of artificial double stars to be used as test-objects were accurately cut from a thin plate, the dimensions being as follows:

Pair	Diameter of Circles mm	Separation of Centers mm
C	1.08	3.39
D	6.64	7.98

The double-star images to be studied were obtained by photographing test-objects C and D in a precision camera as in previous experiments. The exposure times were 1^s, 2^s, 4^s . . . . 4^m in the case of object C, giving a series of double stars, the diameter of whose components varied regularly from 0.07 mm to 0.18 mm, varying somewhat with developer and development time. Many plates were exposed in this way and developed for different lengths of time in different developers in the hope of finding a variation in the effect which would lead to an understanding of its nature. In this preliminary series of experiments no certain variation with developer and development time was disclosed. In Table IV, giving the result of these measures, the mean result from all plates and all developers is given, eleven plates in all being measured.

TABLE IV

RESULTS FROM DOUBLE-STAR TEST-OBJECT C

Exposure Time	Separation of Edges	Diameter of Images	Separation of Centers	Computed Turbidity Correction
	mm	mm	mm	mm
1.0 sec.	0.096	0.076	0.1724	. . . . .
1.9	.084	.088	.1720	. . . . .
3.8	.071	.101	.1720	. . . . .
7.5	.060	.112	.1717	. . . . .
15.0	.048	.124	.1724	0.0000
30.0	.036	.136	.1724	+ .0002
60.0	.024	.150	.1749	+ .0008
120.0	.016	.160	.1764	+ .0015
240.0	0.010	0.171	0.1813	+0.0026

The fourth column of this table shows a strong and undoubted "repulsion" of centers of such a magnitude as to completely overshadow the so-called gelatine and turbidity "attraction" effects. The turbidity effect is given in the last column, computed from formula (7) with $m = 12.5$.

Test-object D.—This test-object was designed for the purpose of finding out to what extent the repulsive effect shown in the case of test-object C depends on the *size* of the component images. The measurements of only one plate are given in Table V, as they are illustrative of the average result obtained. Development was in pyro-soda. The measurement in the case of test-object D was made in a different way from that of object C, for it can be objected

that the result obtained for C was due to psychological causes, the bisection of centers in the process of measurement being influenced in a varying systematic manner by the presence of the neighboring

TABLE V

RESULTS FROM DOUBLE-STAR TEST-OBJECT D

Exposure Time	Separation of Edges	Separation of Centers	Mean Longitudinal Diameter D_1	Mean Transverse Diameter D_2	D_2-D_1
sec.	mm	mm	mm	mm	mm
1.0.....	0.068	0.413	0.346	0.350	0.004
1.9.....	.059	.413	.354	.358	.004
3.7.....	.052	.412	.360	.368	.008
7.5.....	.049	.416	.367	.376	.009
15.0.....	.044	.419	.374	.387	.013
30.0.....	.041	.422	.380	.396	.016
60.0.....	.035	.425	.389	.402	.013
120.0.....	0.032	0.428	0.396	0.411	0.015

or comparison image. Accordingly, in the case of object D, the settings of the micrometer thread were made on the edges of each star, and the separation of centers was computed. This also gives

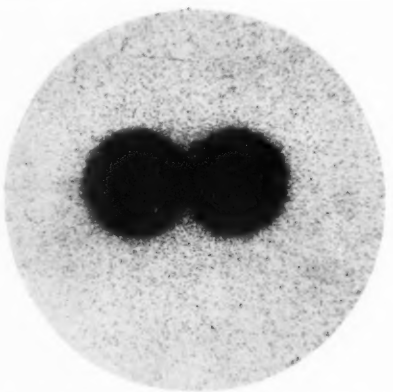


FIG. 6.—Images of a double star in contact

the longitudinal diameter of each stellar image. As a check, the transverse diameter of each stellar image was measured, for a reason which will appear in Table V.

The repulsion is seen to be greater than in the case of test-object C, although the minimum separation of edges is greater. This

was to be expected, if the explanation of the phenomenon presently to be given is the correct one. In order to eliminate from D_2-D_1 any error in perfect roundness of the holes in the test-object, an auxiliary series of exposures was made in which each hole of the test-object was covered in turn. The mean of a series of exposures made in this way gave $D_2-D_1=0.004$ mm. This correction has been applied in the foregoing table. It is seen that as the images approach they become decidedly oval in form, the greater axis being transverse. An enlargement of these images is shown in Figure 6, in which the oval form is apparent to the eye.

The Kostinsky effect on spectral emission lines.—In order to investigate the Kostinsky effect on spectral emission lines, a test-object E was made having but one pair of slits of the following dimensions:

Width of slits	0.36 mm
Distance between centers of slits	2.94 mm

On account of the importance of the Kostinsky effect on spectral lines, an extensive series of experiments was made with this test-object. Five developers were used. In all twenty plates were exposed, four for each developer. The plates were measured both wet and dry. In measuring the wet plates, pointings were made through the back, in order to eliminate errors due to capillarity. The exposures on each plate were timed to include images not far from threshold size at one end to images nearly in contact at the other end of the series.

The results of Table VI are plotted in Figure 7 (p. 367). In the first place it is noticed that the gelatine effect (wet-dry) is practically the same for all developers. Since the minimum separation of edges is 0.028 mm, the maximum turbidity effect is negligible (Table I). Accordingly the curves (wet) give the true Kostinsky effect, it being assumed from previous work that the gelatine effect is not present in the wet condition of the plate. It is possible that further work on the subject may modify this assumption.

There appears from the curves to be considerable variation of the Kostinsky effect with developer. The effect is greatest for pyro developer, and smallest for metol-hydroquinone. The remarkable fact is brought out that in the case of measures on the

dry plate, one to which naturally the greatest interest is attached, there is first an attraction, followed by a repulsion as the separation becomes smaller. This may serve in part to explain the contradictory results obtained by various investigators quoted in the

TABLE VI

RESULTS FROM TEST-OBJECT E (SPECTRAL DOUBLES)

Developers: *a*, caustic hydroquinone; *b*, pyro-metol; *c*, metol-hydroquinone; *d*, pyro; *e*, ferrous oxalate.

Exposure Time	Separation of Centers					Separation of Adjacent Edges				
	a	*b*	*c*	*d*	*e*	*a*	*b*	*c*	*d*	*e*
	Measured Dry									
	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
1.0 sec.	0.1500	0.1480	0.1500	0.1498	0.1502	0.125	0.122	0.128	0.128	0.128
1.9	.1490	.1475	.1490	.1485	.1498	.116	.112	.120	.119	.120
3.7	.1482	.1472	.1492	.1478	.1483	.105	.101	.107	.110	.110
7.5	.1478	.1463	.1488	.1473	.1465	.094	.091	.095	.098	.099
15.0	.1480	.1450	.1485	.1470	.1472	.083	.076	.085	.088	.085
30.0	.1478	.1465	.1472	.1473	.1478	.072	.065	.072	.076	.073
60.0	.1470	.1445	.1490	.1458	.1458	.060	.055	.061	.068	.063
120.0	.1470	.1442	.1468	.1455	.1433	.047	.044	.054	.055	.052
240.0	.1470	.1457	.1482	.1465	.1438	.037	.033	.044	.048	.042
480.0	0.1490	0.1470	0.1500	0.1492	0.1470	0.030	0.028	0.035	0.038	0.036
Means	0.1481	0.1462	0.1487	0.1475	0.1470	.....	.....	.....	.....	.....
	Measured Wet									
1.0 sec.	0.1510	0.1488	0.1502	0.1512	0.1512					
1.9	.1515	.1480	.1510	.1520	.1512					
3.7	.1510	.1507	.1522	.1502	.1493					
7.5	.1498	.1503	.1525	.1520	.1498					
15.0	.1512	.1500	.1522	.1510	.1505					
30.0	.1515	.1502	.1540	.1508	.1512					
60.0	.1522	.1512	.1543	.1525	.1507					
120.0	.1520	.1493	.1533	.1545	.1502					
240.0	.1555	.1528	.1545	.1552	.1515					
480.0	0.1560	0.1575	0.1562	0.1582	0.1538					
Mean	0.1522	0.1509	0.1530	0.1528	0.1509					
Mean Wet-Dry	0.0041	0.0047	0.0043	0.0053	0.0039					

introduction. The explanation is simple. In the first stages the gelatine attraction is stronger than the Kostinsky repulsion, while in the latter stages, when the separation becomes less than about 0.06 mm, the Kostinsky repulsion predominates. The behavior of ferrous oxalate is curious, and needs to be checked. It is to be

noted that in the case of all developers, development was fairly complete, having been pushed to the point where fog became noticeable.

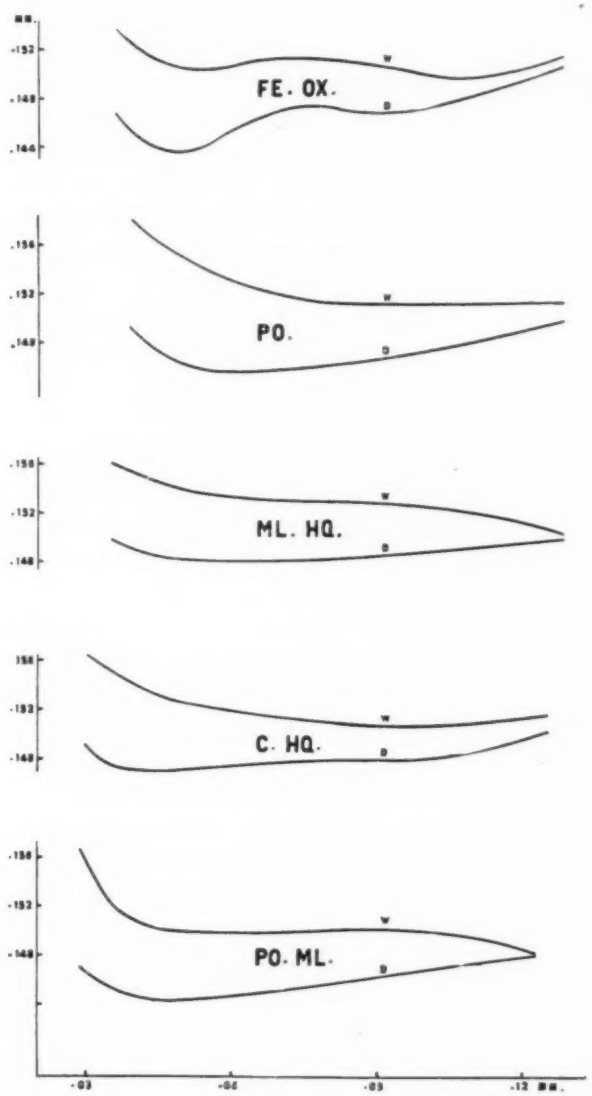


FIG. 7.—Separation of close emission-lines for various developers. Abscissa, edge separation.

Another series of experiments is planned which will allow the curves to be followed closer to the point of contact. In the present instance this could have been done simply by increasing the exposure, but the resultant lack of sharpness of the outline would have made accurate measurement difficult. It is simply a matter of choosing test-objects of suitable dimensions, to get contact simultaneously with sharpness of outline.

As to the cause of the Kostinsky effect, it seems reasonable to assume that it is a *developer* effect and but another manifestation of the Eberhard effect.[1] In the process of development, reaction products are formed which are known to have a powerful restraining

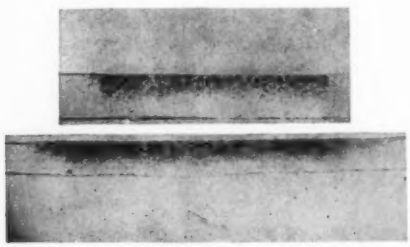


FIG. 8.—Two sections of photographic images showing Eberhard effect

action on development. The bright ring surrounding strong, sharp negative-images is one manifestation of this action. The action may be something more than a simple, restraining one, for the bright ring is very often seen around minute stellar images. The action must accordingly be a positive and permanent one, the products of development acting on the image in its immediate neighborhood as soon as formed, the effect spreading to adjacent regions as they diffuse, until their concentration becomes too low to be effective. With these assumptions, the Kostinsky "repulsion" of neighboring images is easily explained. Consider a pair of adjacent images. As development goes on, the liberated products of development pour into the intervening space from both sides, restraining or inhibiting development of the latent image in this region, as explained above. But, on the "far" sides, the concentration of the products of development is only one-half. There

[1] *Physikalische Zeitschrift*, **13**, 288, 1912.

is less restraining action of the latent image in these regions, therefore. The net result of this non-symmetrical action on each image is an apparent repulsion or retrocession of centers. This action is very well illustrated in Figure 6 which is an enlargement of a pair of close images, the oval form being quite perceptible. In Figure 8 the action *downward* in the film is shown. It will be noticed that the density or amount of silver is less in the center of the image than at the edge. This is the true Eberhard effect, of dependence of *density* of image on its size. The Kostinsky and Eberhard effects are considered to be but different manifestations of a common phenomenon: in the Kostinsky effect we are concerned with the developer effect on size of image, in the Eberhard effect with the developer effect on density of image.

Up to this point a seemingly confused mass of material has been presented, the results from which appear more or less contradictory: in some cases the net result of an experiment is a repulsion, in others an attraction. It is therefore pertinent to inquire if there is any principle governing the *net* effect. It will be noticed that in general in those cases where a repulsion has been obtained, the images were formed by *overexposure;* and in those cases where an attraction was found, the exposures have been normal. This is equally true with respect to the results obtained by other investigators quoted above, and those obtained by the writer as just described. As to the cause, it is only necessary to assume that in overexposure the retarding action of the products of development is very great, or that it is directly proportional to the exposure. This is a not unreasonable assumption. Instead of the separation of images, therefore, being the only controlling factor in the Kostinsky repulsion, or development effect, as has heretofore been assumed, an equally powerful factor is the exposure value.

The conclusion is that in average work a slight *contraction* in separating distance of neighboring stellar images or bright emission lines in spectra is to be expected. But on account of variations in exposure from normal to overexposure, it is by no means certain in any given case that contraction will result: there may be no effect, or there may even be a repulsion. Summing up, if exposures are kept at a minimum, errors exceeding two or three microns need

not be feared. The importance of reducing the exposures to the lowest possible value is to be emphasized.

Behavior of close absorption lines.—Upon applying the reasoning used in the treatment of close double stars and bright-line spectra or emission lines to the case of absorption lines, important differences arise in the case of all three of the factors of turbidity, gelatine effect, and development effect. This is especially true in respect to the turbidity effect. Consider two neighboring absorption lines, separated by an illuminated strip. The intensity of illumination in this area must be less than in the regions adjacent to the "far" boundaries of the lines. This becomes clear when it is noted that in the case of a turbid medium such as a photographic emulsion the intensity of the illumination at any point within it is the resultant of the flux at the surface combined with flux from the surrounding regions, which has been bent from its normal course by diffraction and reflection. In the case in hand, the surrounding regions are the unilluminated absorption lines which lie on each side of the bright area. There is therefore a deficiency of illumination at the adjacent edges of the absorption lines leading, in the developed image, to an apparent broadening of each line asymmetrically. Owing to the factor of turbidity, therefore, but in quite a different manner from the action of turbidity on emission lines, the distribution of light leads to an apparent attraction of spectral absorption lines. While the amount of the attraction in the case of emission lines can be calculated, as shown above, any simple mathematical treatment of the corresponding problem of absorption lines does not seem possible. Only in a qualitative sense can the attraction be proved existent. It is quite evident, moreover, that the action is greater the closer the lines, so that the general law of the action in both cases appears to be the same, although explained physically in different ways.

Unlike the turbidity action, the disturbing action of the gelatine seems to be reversed in passing from emission to absorption lines. Recalling that the movement of the edge of an image in the process of drying is always toward the region of greater density, and noting further that the weak density separating the absorption lines has less of a "pull" than the stronger density adjacent to the far edges,

it follows that absorption lines are apparently repulsed owing to their asymmetric broadening in drying. It is quite likely that the action is weaker than in the case of bright-line spectra, for in order to preserve the definition and even the visibility of absorption lines the exposures given are relatively weak and the developed densities low. The writer has previously shown[1] that the gelatine effect diminishes as the density of the image becomes less. In bright-line spectra, on the contrary, the visibility is improved by long exposures, so that the central diffraction-image may be in this case very much overexposed. The chemical actions in development are accordingly more intense, leading to greater disturbance than in the case of absorption lines.

It remains to consider the development disturbance in close absorption lines. Applying the hypothesis used in the previous cases of double stars and emission lines, namely, that the edge of a silver image loses density in development by an amount proportional to the chemical activity going on in the region back of the edge, it will be seen that the far edges of absorption lines suffer to a greater extent than the near or adjacent edges, so that here again an apparent repulsion takes place. As in the case of the gelatine effect, the amount of the action should be less for absorption than for bright-line spectra, owing to the low densities concerned.

In addition to the three disturbances just considered which are present in both emission and absorption spectra, there is a fourth disturbance which is effective only in the case of absorption lines. On account of the great extent of the illuminated area of the plate back of the non-adjacent edges of the absorption lines, it is to be expected that the distribution or falling off in light-intensity at these edges is different from that at the near or contiguous edges. From general considerations the light-curve at the far edges should be flatter, or κ, in the intensity equation (1), smaller. Accordingly m, the rate of growth of these edges with exposure, is greater (equation [2]). The result is an apparent attraction of the lines. The effect is enhanced by halation.

Considering the totality of the disturbing actions concerned in the case of absorption lines, it may be predicted that errors in

[1] *Astrophysical Journal*, **52**, 104, 1920.

the measurement of adjacent absorption lines are small. It is accordingly difficult to explain the difference between the Rowland and the Mount Wilson measures, found by St. John, as being due to the phenomena here considered, which strengthens the case for the "personality" explanation of the differences, or at least a portion of them. The anomalies found by Goos are more of the order that might be expected.

The writer has made a series of laboratory experiments on artificial absorption lines, the results from which will now be given. In a first experiment a series of nine pairs of lines was arranged on the test-object (called F) to be photographed, the separation of

TABLE VII

ABSORPTION LINES, VARYING SEPARATION

PAIR	WET			DRY				WET-DRY
	S_o	Sc	Diff.	S_o	Sc	Diff.	E	
	mm	mm	mm	mm	mm	mm	mm	mm
1.....	0.0793	(0.0793)	(0.0000)	0.0800	(0.0800)	(0.0000)	0.035	−0.0007
2.....	.0703	.0713	− .0010	.0713	.0719	− .0006	.031	− .0010
3.....	.0660	.0669	− .0009	.0673	.0675	− .0002	.029	− .0013
4.....	.0557	.0565	− .0008	.0560	.0570	− .0010	.027	− .0003
5.....	.0520	.0531	− .0011	.0527	.0536	− .0009	.024	− .0007
6.....	.0487	.0487	.0000	.0490	.0491	− .0001	.022	− .0003
7.....	.0417	.0435	− .0018	.0420	.0439	− .0019	.021	− .0003
8.....	.0410	.0427	− .0017	.0423	.0431	− .0008	.020	− .0013
9.....	0.0343	0.0374	−0.0031	0.0353	0.0378	−0.0025	0.012	−0.0010

the widest pair being 1.50 mm and of the closest 0.71 mm. The width of the lines is equal to the separating spaces. The distances on the test-object were accurately measured, so that, assuming no optical distortion, the relative correctness of the reduced separations in the photograph can be tested by simple proportion. Table VII shows the results obtained. Each measured distance given is the mean of measurement of nine separate exposures.

S_0 is the measured separation of centers of the lines; S_c is the value computed as above described. E is the separation of adjacent edges. Results are given for plates measured both wet and dry. The prediction that the actions would be small is verified. The net result is an apparent *attraction* of close, spectral absorption lines. Accordingly in this case the repulsive developer action must be relatively small.

It is important to obtain data on the behavior of absorption lines for overexposures, as has already been done for double stars and emission lines. For this purpose two test-objects G and H were made, composed of parallel opaque strips about 6 mm wide. In G the strips were placed far apart, in H close together. The dimensions are as follows:

	G	H
	mm	mm
Separation of centers of strips.....	8.694	6.620
Separation of adjacent edges.....	2.414	0.400

These were photographed in the camera as before, with exposure times from 1 to 120 seconds and completely developed in Process developer. Two series of each were made and each plate measured twice, so that the numbers given below are the means of four separate values. In order to eliminate personality error, settings were made on the four edges, from which the separation of centers was computed. In the shortest exposure (1 sec.) the densities were low and of the order obtained in practical work.

TABLE VIII

ABSORPTION LINES WITH INCREASING EXPOSURE

EXPOSURE TIME	G			H			WIDTH OF LINES
	S Wet	S Dry	E	S Wet	S Dry	E	
sec.	mm	mm	mm	mm	mm	mm	mm
1.....	0.453	0.457	0.125	0.347	0.350	0.008	0.34
2.....	.453	.456	.129	.346	.351	.013	.34
4.....	.449	.455	.136	.345	.349	.018	.33
7.....	.449	.458	.149	.341	.347	.024	.32
15.....	.451	.457	.161	.337	.345	.036	.31
30.....	.448	.454	.175	.333	.341	.047	.30
60.....	.449	.454	.190	.333	.341	.060	.28
120.....	0.448	0.455	0.188	0.331	0.337	0.070	0.27
Mean	0.450	0.456	.....	.....	.....	.....	.....

In the case of the wide pair G, no certain variation with exposure time is apparent. But in the case of the close pair a strong attraction with increasing exposure, or else a repulsion with diminishing separations, is apparent. In order to decide which of these alternative statements is the correct one, recourse may be had to the

measured separations of the lines on the test-object itself, already given. We find in this way:

$$\text{Separation of H (wet)} = 0.453 \frac{6.620}{8.694} = 0.345 \text{ mm}$$

$$\text{Separation of H (dry)} = 0.457 \frac{6.620}{8.694} = 0.348 \text{ mm}$$

Thus, except for a slight repulsive action, which can be neglected for the moment, the separations in the case of test-object H are correctly given for the short exposures even though the edges of the lines are nearly in contact. In the case of the heavy exposures on H the lines are relatively far apart and yet a strong attraction has taken place, amounting to 13 μ. This is very readily explained as due to the fourth disturbing factor outlined above, namely, the greater turbidity on the far sides of the absorption lines combined with halation. In fact, the greater sharpness of the inside of each absorption line was apparent in the measurement. This cannot be considered an optical lack of sharpness since the field angle for the outside edge is only 6′.

A sufficient number of experiments have been described to show the great complexity of the mutual action of adjacent images. It has been the aim of the paper to cover the field only in a general way in order to disclose the factors of importance. A partial solution of the problem of eliminating mutual attractions and repulsions has been indicated. It remains for future work to make a detailed study of the action of various developers in the hope of securing one giving correct or normal development of the latent image.

EASTMAN KODAK COMPANY
ROCHESTER, N.Y.
February 3, 1921

OBSERVATIONS OF THE NEBULAR LINES IN THE SPECTRUM OF THE LONG-PERIOD VARIABLE STAR R AQUARII[1]

By PAUL W. MERRILL

ABSTRACT

Discovery of nebular lines in the spectrum of R Aquarii.—This star has a typical Md spectrum similar to that of about 85 per cent of all long-period variable stars. In October, 1919, the bright nebular lines λλ 4363, 4658, 4959 N_2, and 5007 N_1, and the helium line λ 4471, which also occurs in nebulae, were found to be superposed on the Md spectrum. Later observations have shown that these lines do not share in the changes of intensity exhibited by the light of the variable star, although they appear to emanate from the same object.

Intensities and *displacements* of the Md and nebular lines are given in Table I.

R Aquarii (R.A. 1900 = $23^h38^m.6$, Dec. 1900 = $-15°50'$) has been known as a variable star since 1811. The photometric data, according to the Harvard College Observatory, are as follows: maximum magnitude 6.2; minimum magnitude 11.0; period 385.5 days. The same authority states that R Aquarii has the broadest minimum of 75 long-period variables whose light curves were carefully studied. Its mean light-curve has a broad, flat minimum and a very rapid rise to maximum.

The Harvard objective-prism photographs have shown the spectrum to be of the same class as that of 85 per cent of the long-period variables, namely, Md. Spectra of this class are marked by bright hydrogen lines superposed upon a continuous spectrum which is notched by numerous absorption bands of titanium oxide. Variations in the relative intensities of the bright Hγ and Hδ lines are common in Md spectra, and have been found in the spectrum of R Aquarii.

So far as known, the first slit spectrogram of this object was secured on October 16, 1919, with a single-prism spectrograph attached to the 100-inch Hooker telescope. This showed, in addition to the usual Md spectrum, several bright lines characteristic of gaseous nebulae. Three such lines were conspicuous, namely,

[1] *Contributions from the Mount Wilson Observatory*, No. 206.

λ 5007 N_1, λ 4959 N_2, and λ 4363, while λ 4658 and λ 4471 He were faintly visible. Plate IX reproduces four spectrograms.

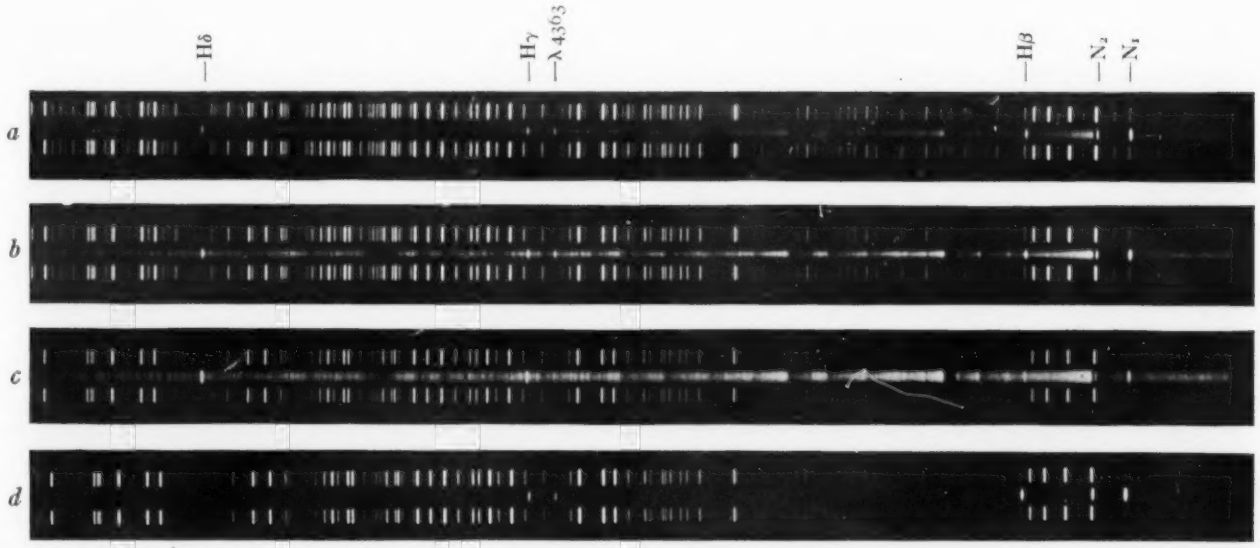
On this date the star was of magnitude 8.3; during the next fifteen days it brightened rapidly, and then remained nearly constant at magnitude 6.9 for about two months, after which a rapid decline took place.[1] This maximum appears to have been unusually broad and flat. The spectrographic observations following October 16, 1919, showed that the nebular lines did not share in the increase in intensity exhibited by the bright lines of the Md spectrum. No well-exposed plate was secured in the short interval *after* maximum before the star was lost in the evening sky, but such plates as were obtained indicated that the nebular lines had begun to regain their previous intensities with respect to the Md spectrum. By the time observations could be resumed in the morning sky in June, 1920, the star had faded to the tenth magnitude and was not much above its minimum brightness. Nevertheless, the chief nebular lines could be photographed with about the same exposure times as at maximum, although the continuous spectrum was practically absent, even with considerably longer exposures.

The approximate relative intensities of the emission lines as photographed with a single dense flint prism on Seed 30 plates are given in Table I.

The Md spectrum of R Aquarii near maximum light contains the bright hydrogen lines Hβ, Hγ, and Hδ, which are superposed upon corresponding bright lines associated with the nebular spectrum. This is made clear by a study of the manner in which the intensities and displacements of these lines vary during the light cycle. At maximum the Hγ and Hδ lines of the Md spectrum are many times as strong as the corresponding nebular Hγ and Hδ lines, but at minimum they appear to be of negligible strength compared with these nebular lines. The relative intensities of the hydrogen lines in the Md spectrum of R Aquarii at maximum and the disappearance of these lines at minimum are not at all unusual for this type of spectrum. The bright magnesium line

[1] Mr. Leon Campbell, of Harvard College Observatory, has kindly supplied the photometric data.

PLATE IX



SPECTROGRAMS OF THE LONG-PERIOD VARIABLE STAR R AQUARII, SHOWING LINES CHARACTERISTIC OF GASEOUS NEBULAE

Secured with a one-prism spectrograph of 18-inch camera-focus attached to the 100-inch Hooker telescope.

(*a*) October 16, 1919; 43 days before maximum; magnitude 8.3.

(*b*) October 19, 1919; 40 days before maximum; magnitude 8.2. Strömberg, observer.

(*c*) November 1, 1919; 27 days before maximum; magnitude 7.0. Adams, observer.

(*d*) September 4, 1920; 281 days after maximum, 47 days after minimum, and 109 days before the next maximum. Magnitude 10.2.

λ 4571, which was observed in the spectrum of R Aquarii at minimum, is characteristic of Md stars at this phase.[1]

The relative intensities of the lines in the nebular spectrum do not appear to be precisely matched in any nebula observed by Wright[2] although there are several objects in his list that are similar in some particulars. The decrease in intensity in the Balmer series of hydrogen in passing from Hγ to Hδ is rapid as compared with the nebulae. Other noteworthy features are the strength of λ 4363, the presence of λ 4658, and the absence (or

TABLE I

INTENSITIES AND DISPLACEMENTS OF LINES IN THE SPECTRUM OF R AQUARII

WAVE-LENGTH IA	IDENTIFICATION	INTENSITIES		DISPLACEMENTS (km/sec.)	
		Nebular	Md (max.)	Nebular	Md
4101.74	Hδ	1	60	(− 6)	−32
4340.47	Hγ	5	30	−12	−33
4363.21*	Nebular	4	.....	−25	.....
4471.48	He	1	.....	(−10)	.....
4571.11	Mg	.....	.....	.....	(−34)
4658.2*	Nebular	1	.....	(−15)	.....
4861.33	Hβ	10	5	−10	.....
4958.91†	Nebular (N_2)	11	.....	− 7	.....
5006.84†	Nebular (N_1)	20	.....	− 7	.....
Absorption lines	.....	.....	.....	.....	−19

* Wright, *Publications of the Lick Observatory*, **13**, 183, 1918.

† Campbell and Moore, *Lick Observatory Bulletins*, **9**, 9, 1916.

relative weakness) of λ 4686. An additional nebular line, λ 3869, was observed in the spectrum of R Aquarii by Moore[3] at the Lick Observatory on November 3, 1919. Light of this wave-length is strongly absorbed by the dense flint glass of the Mount Wilson spectrographs, but faint traces of the line appear to be present on spectrograms taken here on October 17 and December 14, 1919, and September 2, 1920. Wright has made some very interesting comments[4] on the absence of the companion line λ 3967, and on some other features of this spectrum.

[1] *Mt. Wilson Contr.*, No. 200; *Astrophysical Journal*, **52**, 185, 1921.

[2] *Publications of the Lick Observatory*, **13**, 183, 1918.

[3] *Publications Astronomical Society of the Pacific*, **31**, 309, 1919.

[4] *Ibid.*

In spite of the extraordinary nature of this combination spectrum, various observations appear to show that the nebular lines and the Md spectrum both emanate from the same star. Notes on these observations have been published[1] and need not be repeated here. Radial-velocity data bear on this question, but the measurements made at Mount Wilson and given in Table I do not as yet afford conclusive evidence concerning the nature of the connection between the two spectra. The values in the table, with the exception of those in parentheses, depend upon from seven to eighteen one-prism plates, and should not be much in error. Hβ and the chief nebular lines are in a part of the spectrum which is somewhat unfavorable for accurate measurement, but tests on N.G.C. 7027 and on bright-line stars show that no considerable systematic error is to be expected. All the lines associated with the nebular spectrum probably give the same displacement within errors of measurement, except λ 4363, which is shifted toward the violet by 0.2 A. It is improbable that Wright's value of the wave-length (4363.21 I A) is in error by so large an amount. The lines of the Md spectrum exhibit perfectly typical behavior, the same relative displacement of about 14 km between bright and dark lines having been found in *o* Ceti and in many other Md stars.

The principal facts concerning the line displacements in the spectrum of R Aquarii may be summarized as follows:

Md bright lines	−33 km/sec.
λ 4363, nebular	−25
Md absorption lines	−19
Nebular lines, except λ 4363	−10

The displacements are expressed in kilometers per second merely for convenience. The cause of the differences is not obvious; they may or may not be due to relative motion. One does not readily believe that the object is a long-period binary with an Md star for one component and a planetary nebula for the other.

The question as to whether in Md stars in general the bright lines, or the dark lines, or neither, yield the correct radial velocity

[1] Wright, *Publications Astronomical Society of the Pacific;* Merrill, *ibid.*, **31**, 305, 1919, and **32**, 247, 1920.

of the star is an important one. It is hoped that a statistical investigation, observations for which are now being secured, will indicate the solution. Perhaps the behavior of the nebular lines in R Aquarii will throw a side light on this puzzling phenomenon.

It would be of great interest to know whether the nebular lines have been present in the spectrum of R Aquarii for many years past, or whether they are the results of some recent outburst. The Harvard record, consisting of objective-prism spectrograms of small dispersion, dates from 1893. The fact that the nebular lines are not observable on the Harvard plates, even on those made at minimum light when the continuous spectrum would be very weak, tends to show that they have not been so strong at all times as they have been recently; but the evidence is perhaps not quite conclusive.

At present we have so little knowledge of the chemical and physical interpretation of the nebular lines that the meaning of their presence in R Aquarii cannot be stated. Since the Md spectrum probably arises under low-temperature conditions, the possibility of the production of the chief nebular lines N_1 and N_2 and of λ 4363 without intense conditions of excitation is suggested. It may be of significance in this connection that λ 4686, which in the laboratory requires high excitation for its production, has not been observed in R Aquarii. Laboratory experiments on long columns of gases under low excitation might not be amiss.

MOUNT WILSON OBSERVATORY
March 1921

ON SYSTEMATIC DISPLACEMENTS OF LINES IN SPECTRA OF VENUS[1]

By CHARLES E. ST. JOHN and SETH B. NICHOLSON

ABSTRACT

Systematic displacements of the solar lines in spectra of Venus.—Under certain conditions of observation there are line displacements to the violet of a few thousandths of an angstrom when comparison is made with the position of the lines in the spectrum of integrated skylight. Other conditions remaining constant, the displacements are greater at low than at high altitudes.

Atmospheric refraction.—The correlation with the altitude at the time of observation points to refraction as the controlling factor rather than to a repulsive "earth-effect" acting on the solar vapors as suggested by Evershed. The altitude correlation is represented by $\Delta\lambda 10^{-3} = 1.4 - 1.0 \cot h$. The residuals, after removing the effect depending upon altitude, correlate equally well with the semidiameter D of Venus, the phase angle i, or the angle VSE. The observations are satisfactorily represented by the relation $\Delta\lambda 10^{-3} = 1.3 - \frac{8.5 \cot h}{D}$ which is deduced from the assumption that the observed displacements are caused by unsymmetrical illumination of the slit due to the separation of the visual and photographic images by atmospheric refraction, and that the unequal illumination is a function of the diameter of the image and the width of the slit.

Superposed skylight.—Spectroscopic observations of Venus beginning at sunset or ending at sunrise are not measurably affected by superposed skylight.

I. INTRODUCTION

Evershed and Royds have proposed an interpretation of the differences between terrestrial and solar wave-lengths[2] based solely on radial velocity. They assume that the solar gases at all points on the sun are receding from the earth. This means, they say, an "earth-effect"—an actual repulsion of the solar gases by the earth, and not by other planets. Through such earth-induced movements of the solar vapors Evershed has attempted to explain displacements of the Fraunhofer lines at the center, over the disk, and at the limb of the sun, discarding interpretations involving pressure-effects, radial convection currents, anomalous dispersion, and the Einstein gravitational shift.[3] No explanation of an "earth-

[1] *Contributions from the Mount Wilson Observatory*, No. 208.

[2] *Kodaikanal Observatory Bulletin*, No. 39, 1916. [3] *Observatory*, **43**, 153, 1920.

effect" is suggested and the arbitrary and extraordinary nature of the assumption is recognized; yet Evershed is so convinced of its reality that he says,[1] "Whether we like it or not, it seems necessary to admit that the Earth *does* affect the Sun, causing a movement of the gases analogous to that taking place in a comet." This view he believes is confirmed by his observations upon the spectrum of Venus. The idea of an apparent "earth-effect" upon solar phenomena is not new. Sykora[2] in 1897 called attention to a predominance of eastern prominences, and in 1907 Mrs. Maunder's paper "An Apparent Influence of the Earth on the Numbers and Areas of Sun-Spots in the Cycle 1889–1901" was communicated to the Royal Astronomical Society.[3]

According to Evershed's assumption, the displacements observed in the light from the earth-facing hemisphere of the sun should differ from those observed in the light from any other hemisphere; for example, from the hemisphere facing Venus.

He finds that when the angle Venus-sun-earth is small the wave-lengths in the spectrum of Venus are slightly shorter than those in direct sunlight; that this difference increases as the angle *VSE* increases; that when the angle is 90° the shortening equals the difference, sun *minus* arc, the wave-lengths from Venus and in the terrestrial source then becoming equal; and that for larger angles the displacements relative to the arc are to the violet; that is, in the light from the earth-facing hemisphere of the sun the Fraunhofer lines are displaced toward longer wave-lengths, while in the light from the opposite hemisphere the displacements are toward the violet when compared with the terrestrial source.[4] In order to obtain independent observational data bearing upon these extraordinary results, we have carried out two series of observations, the first in 1919 with Venus east of the sun, and the second in 1919–1920 with Venus west of the sun.

II. INSTRUMENTS AND METHODS

The observations were made with the Snow telescope of 60-foot focus in connection with a Littrow grating-spectrograph, focus

[1] *Observatory*, **42**, 52, 1919.

[2] *Memorie della Società degli Spettroscopisti Italiani*, **26**, 161, 1897.

[3] *Monthly Notices*, **67**, 451, 1907.

[4] *Observatory*, **43**, 156, 1920.

18 feet. The horizontal beam from the 2-foot concave mirror is directed downward by a 45° flat upon the slit of the spectrograph installed in the constant-temperature pit recently added to the equipment of the Snow telescope. The diameter of the image of Venus varied from 1.3 to 3.3 mm. The slit was 0.05 mm wide, its position being, in general, approximately normal to the terminator. The grating was ruled by Anderson and kindly loaned by Professor R. W. Wood, of the Johns Hopkins Physical Laboratory. The ruled surface is 95 mm × 170 mm; it is very bright in the first order and, as used, gives a linear dispersion of 3 A per mm. The collimating lens has an aperture of 6 inches.

Exposures were made upon the iron arc simultaneously with exposures upon Venus, the sky, or the center of the sun. In 1919 the center of an enlarged image of the arc was projected upon the slit, the intensity being controlled by a rotating sector and ray filter. In the second series a ground glass was placed in front of the arc, and the integrated light was used. Any errors in the wave-lengths of the reference lines would affect the measurements of Venus and of the sky in the same way, leaving the relative wave-lengths dependable. The iron lines in Table I were used as standards of reference.

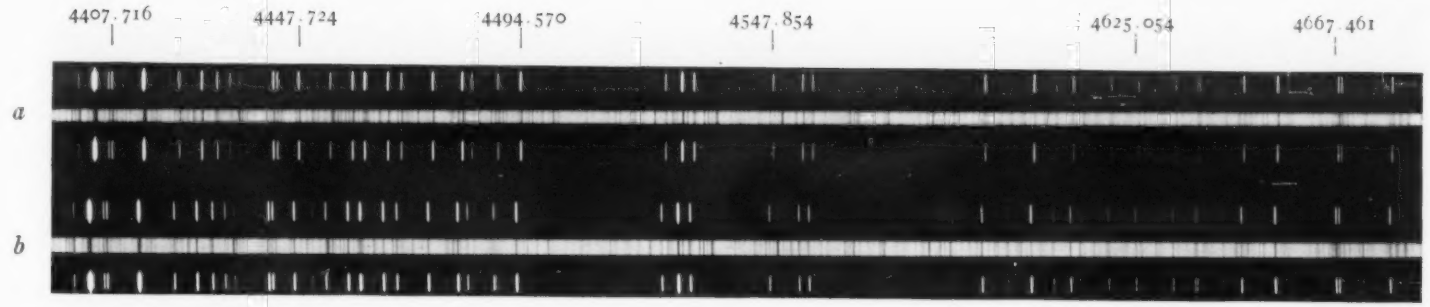
TABLE I

REFERENCE LINES—INTERNATIONAL SYSTEM

4375.934 A	4466.557 A	4592.658 A
4407.716	4494.570	4625.054
4427.314	4525.146	4647.440
4447.724	4547.854	4667.461

The wave-lengths of 30 lines were measured in the spectra of the center of the sun, of skylight, and of Venus. The spectrograms were measured red right and red left and reduced by identical methods. In all, 56 spectrograms of Venus were secured, 41 of the sky, and 9 of the sun. It early became evident that the center of the sun and the integrated skylight give the same wave-lengths, the contribution of the limb-displacements to the red being inappreciable in the integrated light. The sky *minus* center for the 30 lines is +0.0001 A. The lines measured are given in Table II.

PLATE X



PHOTOGRAPHS OF THE SPECTRA OF VENUS AND THE SKY

a. Venus, Plate V119, 1919, November 21, $17^h\ 17^m - 18^h\ 21^m$ P.S.T.
b. Sky, Plate V115, 1919, November 20, 19 45 −20 45 P.S.T.
The comparison spectra are of the iron arc. Enlargement 2.

These lines were selected irrespective of whether they are blends or not, as they were to be used for relative wave-lengths only.

The data for the individual plates are given in Tables III and IV. The time of observation has been taken as the mean of the beginning and the end of the exposure, except in a few cases where clouds interrupted. No attempt has been made to obtain the mean time of the effective exposure, which would be somewhat different from that used on account of the change in atmospheric

TABLE II

LINES MEASURED IN SPECTRA OF VENUS AND THE SKY

Rowland λ	Int.	Element	Limb-Center	Rowland λ	Int.	Element	Limb-Center
4376.107...	6	Fe	+0.005	4527.101...	3	Ca?	+0.007
4422.741...	3	Fe, Y	.....	34.953...	4	Ti	+0.004
35.851...	4	Ca	+0.006	48.024...	3	Fe	+0.008
42.510...	6	Fe	+0.006	54.211...	8	Ba	+0.008
43.976...	5	Ti	+0.008	63.939...	4	Ti	+0.008
47.892...	6	Fe	+0.005	71.275...	5	Mg	+0.007
51.752...	3	Mn	.....	84.018...	4	Fe−	+0.012
56.030...	5	Mn_2,Ca_3	.....	4602.183...	3	Fe	.....
68.663...	5	Ti−	+0.007	03.126...	6	Fe	.....
76.214...	7	Fe_4, Ag_3	.....	25.227...	5	Fe	.....
82.376...	8	Fe_5, Fe_3	+0.004	26.358...	5	Cr	.....
84.392...	4	Fe	.....	29.521...	6	Ti-Co	.....
85.846...	3	Fe	.....	30.306...	4	Fe	.....
94.738...	6	Fe	+0.010	51.461...	4	Cr	.....
4508.455...	4	Fe?,−	+0.011	52.343...	5	Cr	.....

absorption. The third column gives the difference between the measured wave-lengths in the spectrum of Venus and those of the same lines in the spectra of the sky, corrections for velocity having been applied in both cases. The difference between the heliocentric longitudes of Venus and the earth was used as the angle *VSE*. The quantity *h* is the true altitude of Venus. The phase angle of Venus is indicated by *i* and the semi-diameter by *D*.

The velocity of Venus relative to the earth was obtained from the hourly variation in the logarithm of the geocentric distance. The relative velocity of Venus and the sun was calculated in the same way from the variation in the logarithm of the radius vector of Venus. The velocity of the observer due to the diurnal rotation

TABLE III

OBSERVATIONAL DATA, VENUS EAST OF THE SUN

DATE	EXPOSURE P.S.T.	Δλ V−SKY	h	D	ANGLE *VSE*	i	VELOCITY IN LINE OF SIGHT				Q	SUNSET P.S.T.	PLATE NO.	MEASURER
							V−E	Rot. E	V−S	Total				
		A					km	km	km	km				
1919 April 3..	6^h43^m–8^h3^m	−0.007	14°	6″.3	103°	46°	− 9.48	+0.37	−0.16	− 9.27	4°	6^h13^m	V19	S
7..	7 0 –8 15	−0.004	14	6.4	101	47	− 9.81	+0.36	−0.13	− 9.58	5	6 16	24	S
8..	6 20 –7 20	−0.004	24	6.4	100	48	− 9.88	+0.35	−0.13	− 9.66	5	6 17	25	S
20..	6 35 –8 5	−0.007	22	6.8	93	53	−10.80	+0.35	−0.05	−10.50	77	6 27	30	S, N
21..	6 36 –8 6	+0.003	22	6.8	92	53	−10.88	+0.35	−0.05	−10.58	78	6 27	31	S, N
May 5..	6 48 –8 18	−0.005	24	7.3	82	59	−11.90	+0.34	+0.05	−11.51	264	6 38	38	N
5..	8 30 –9 25	−0.006	8	7.3	82	59	−11.90	+0.35	+0.05	−11.50	264	6 38	39	N
6..	6 38 –8 8	−0.002	27	7.4	81	60	−11.96	+0.33	+0.05	−11.58	84	6 39	40	S
6..	8 16 –9 16	+0.002	11	7.4	81	60	−11.97	+0.35	+0.06	−11.56	84	6 39	41	S
8..	6 48 –7 48	−0.002	28	7.5	80	60	−12.10	+0.33	+0.07	−11.70	265	6 40	49	S
8..	7 51 –9 3	−0.004	15	7.5	80	60	−12.10	+0.35	+0.07	−11.68	265	6 40	50	S
11..	7 3 –7 53	−0.004	27	7.6	79	62	−12.29	+0.33	+0.09	−11.87	87	6 43	61	N
11..	7 58 –9 13	−0.004	13	7.6	79	62	−12.29	+0.35	+0.09	−11.85	87	6 43	62	N
12..	6 53 –7 43	0.000	29	7.7	78	62	−12.36	+0.33	+0.09	−11.94	87	6 43	66	S
12..	7 47 –9 8	−0.004	16	7.7	78	62	−12.36	+0.35	+0.09	−11.92	87	6 43	67	S
31..	7 6 –8 6	−0.001	29	8.8	66	72	−13.36	+0.33	+0.19	−12.84	96	6 57	68	M
31..	8 12 –9 12	−0.005	15	8.8	66	72	−13.36	+0.35	+0.19	−12.82	96	6 57	69	M
June 1..	7 5 –8 5	+0.005	29	8.8	65	72	−13.40	+0.33	+0.20	−12.87	277	6 58	70	N
1..	8 11 –9 11	0.000	15	8.8	65	72	−13.40	+0.35	+0.20	−12.85	277	6 58	71	M
2..	6 40 –7 41	+0.003	34	8.9	64	72	−13.44	+0.32	+0.20	−12.92	97	6 58	72	N
2..	7 58 –9 1	−0.001	17	8.9	64	72	−13.45	+0.35	+0.20	−12.90	97	6 58	73	M
3..	7 0 –8 0	+0.001	30	9.0	64	73	−13.48	+0.33	+0.20	−12.95	278	6 58	77	M
3..	8 10 –9 15	+0.001	15	9.0	64	73	−13.49	+0.35	+0.20	−12.94	278	6 58	78	N
4..	7 3 –7 59	−0.002	30	9.0	63	73	−13.52	+0.33	+0.21	−12.98	98	6 59	79	M
4..	8 7 –9 17	+0.005	16	9.0	63	73	−13.53	+0.35	+0.21	−12.97	98	6 59	80	N
22..	7 34 –8 20	−0.002	24	10.7	51	84	−13.99	+0.35	+0.24	−13.40	105	7 6	83	N, M
July 2..	7 36 –8 24	−0.006	21	11.9	45	90	−14.05	+0.36	+0.23	−13.46	203	7 7	87	M
3..	7 56 –8 56	−0.002	15	12.0	44	90	−14.05	+0.37	+0.23	−13.45	102	7 7	89	S, N
4..	7 36 –8 26	−0.006	21	12.1	44	91	−14.05	+0.36	+0.23	−13.46	89	7 7	90	S, M
20..	7 14 –8 16	−0.005	18	14.8	34	102	−13.61	+0.36	+0.17	−13.08	93	7 2	96	S, M
21..	7 19 –8 29	−0.003	15	15.1	33	103	−13.56	+0.36	+0.17	−13.03	273	7 2	99	S, N

TABLE IV

OBSERVATIONAL DATA, VENUS WEST OF THE SUN

DATE	EXPOSURE P.S.T.	$\Delta\lambda$ V−SKY	h	D	ANGLE *VSE*	i	VELOCITY IN LINE OF SIGHT				Q	SUN-RISE P.S.T.	PLATE NO.	MEASURER
							V−E	Rot. E	V−S	Total				
		A					km	km	km	km				
1919 Nov. 3..	17^h10^m–17^h57^m	−0.003	34°	15″.8	32°	103°	+12.64	−0.29	−0.20	+12.15	270°	18^h14^m	V104	N
4..	15 56 –16 56	+0.011	21	15.6	33	102	+12.69	−0.35	−0.20	+12.14	270	18 14	107	N, M
4..	17 10 –18 12	+0.007	36	15.6	33	102	+12.69	−0.28	−0.20	+12.21	270	18 14	108	S
20..	16 21 –17 21	+0.001	24	12.8	42	90	+13.03	−0.32	−0.12	+12.59	266	18 29	113	N
20..	17 28 –18 28	−0.001	36	12.8	42	90	+13.03	−0.25	−0.12	+12.66	266	18 29	114	N
21..	16 10 –17 11	−0.001	22	12.7	43	90	+13.03	−0.33	−0.11	+12.59	270	18 30	118	S
21..	17 17 –18 21	−0.004	35	12.7	43	90	+13.03	−0.26	−0.11	+12.66	270	18 30	119	S
23..	16 55 –17 45	−0.001	30	12.4	44	89	+13.03	−0.29	−0.10	+12.64	90	18 32	124	S
23..	17 52 –18 37	0.000	39	12.4	44	89	+13.03	−0.22	−0.10	+12.71	90	18 32	125	N
Dec. 8..	17 25 –18 35	−0.001	32	10.7	54	81	+12.91	−0.24	0.00	+12.67	79	18 46	129	S
9..	16 5 –18 20	+0.010	21	10.6	54	80	+12.90	−0.32	0.00	+12.58	80	18 46	131	N
26..	16 32 –17 33	−0.010	17	9.2	64	72	+12.44	−0.31	+0.11	+12.24	88	18 56	133	S
26..	17 37 –18 39	−0.006	27	9.2	64	72	+12.43	−0.24	+0.11	+12.30	88	18 56	134	N
27..	16 45 –17 40	+0.007	18	9.1	65	71	+12.40	−0.30	+0.12	+12.22	269	18 57	137	N
27..	17 45 –18 43	+0.008	28	9.1	65	71	+12.40	−0.23	+0.12	+12.29	269	18 57	138	S
28..	16 42 –17 38	−0.005	18	9.0	65	70	+12.37	−0.30	+0.12	+12.19	269	18 57	141	S
28..	17 43 –18 47	−0.002	28	9.0	65	70	+12.37	−0.23	+0.13	+12.27	269	18 57	142	N
1920 Jan. 29..	18 0 –18 45	−0.003	19	7.2	85	57	+11.10	−0.25	+0.24	+11.09	89	18 51	151	S
31..	16 50 –17 55	−0.015	9	7.1	86	57	+11.02	−0.31	+0.24	+10.95	90	18 50	152	N, M
31..	17 56 –18 46	+0.001	18	7.1	86	57	+11.02	−0.26	+0.24	+11.00	90	18 50	153	N
Feb. 10..	17 40 –18 40	+0.001	14	6.8	92	53	+10.58	−0.28	+0.23	+10.53	96	18 42	155	N
11..	17 25 –18 35	−0.004	13	6.7	92	52	+10.52	−0.29	+0.23	+10.46	276	18 42	157	S
12..	17 20 –18 35	+0.002	12	6.7	93	52	+10.47	−0.30	+0.23	+10.40	277	18 41	159	N
13..	17 38 –18 46	−0.011	14	6.7	93	51	+10.47	−0.28	+0.23	+10.42	97	18 40	161	S
Mar. 11..	17 18 –18 14	−0.004	10	5.9	109	42	+ 9.04	−0.34	+0.12	+ 8.82	110	18 8	166	S

of the earth has been derived in the usual way. Q is the angle between the line joining the cusps and the slit of the spectrograph, measured from the north cusp in the direction of the illuminated portion of the disk to the end of the slit nearest the plate holder. In the first series the red end of the spectrum was on the right as one looked at the slit from the plate holder. In the second series the red was on the left until the end of 1919, when the grating was again reversed. The measurers are identified by the initials S, N, M, indicating St. John, Nicholson, and Miller, respectively.

We take this opportunity to express our appreciation of the assistance given us by Miss Miller in the work of measurement and reduction and by Mr. Edison Hoge in making the observations.

III. DISCUSSION

1. *Correlations.*—Evershed correlated his observations with the angle *VSE* and adopted an interpretation based upon the "very incredible hypothesis"[1] that an "earth-effect" is driving the solar vapors from the earth-facing hemisphere of the sun. Our observations are better correlated with the altitude of Venus at the time of observation. The natural tendency is to use as high an altitude as possible, with the result that the altitude of Venus at the time of observation varies with the angle *VSE*. Our observations, therefore, can apparently be correlated with the angle *VSE* nearly as well as with altitude, but on 18 nights spectrograms were taken at both high and low altitudes: mean high altitude 29°.2, mean low altitude 16°.1, which give $\Delta\lambda$ low $-\Delta\lambda$ high $=-0.0014$ A. Among the low altitude plates are four at mean altitude 24°.2. Pairs in which the low-altitude plates had relatively high altitudes contribute little, on the basis of the correlation with altitude, to the difference shown by the plates at low and high altitudes. On omitting these plates the difference $\Delta\lambda$ low $-\Delta\lambda$ high for the 14 remaining pairs rises to -0.0021 A. As there was no change in the angle *VSE* between the plates of each pair or in the instrumental adjustments, this difference between plates at low and high altitudes is definite evidence of an effect depending in some way on the altitude of the planet, which

[1] *Observatory*, **43**, 156, 1920.

shortened the wave-lengths in the spectrum of Venus observed at low altitude, and indicates that the altitude of Venus is the controlling factor in our observations.

An effect depending on low altitude is naturally associated with refraction, and hence with cot h. To obtain a relation independent of the angle VSE and dependent only upon altitude the coefficient of cot h in the equation

$$\Delta\lambda_1-\Delta\lambda_2=A(\cot h_1-\cot h_2)$$

was derived from each of the 18 pairs of plates. Its value closely approximated 0.001 A. By means of this relation the influence of altitude was eliminated from the 56 original observations. The residual displacements showed a slight variation with the relative position of the earth, sun, and Venus. It should be noted, however, that the angle VSE is only one of the variables dependent upon the relative positions of the three bodies which may be used in seeking such correlations. A satisfactory correlation is made by assuming that the observed displacements are fundamentally due to conditions arising from low altitude, and that the effect is greatest when the image of Venus is smallest. This would be the case if the systematic discrepancies were attributable to unsymmetrical illumination of the slit arising from atmospheric refraction and from the small and varying diameter of the image in relation to width of slit. This is the simplest interpretation of our observations, in that it refers the entire effect to a single rational cause. A solution by least squares for this correlation gives

$$\Delta\lambda 10^{-3}=1.3-8.5\frac{\cot h}{D},$$

where D is the semidiameter of Venus in seconds of arc.

If the angle VSE is used, the observations may be represented by

$$\Delta\lambda 10^{-3}=3.0-1.0\cot h-3.0(1-\cos VSE).$$

By introducing the phase angle i, the following equation may be used:

$$\Delta\lambda 10^{-3}=2.3-1.0\cot h-3.5\cos i.$$

As far as the observations are concerned, these three equations represent them equally well, but the first offers the most reasonable and probable explanation.

In the computation of the velocity corrections the value 8".80 was used for the solar parallax, and the velocity displacements due to rotation of the planet were assumed to be negligible, as would be the case for the long rotation period shown by Slipher's observations.[1] An error in either of these assumptions would not affect the correlations, since deviations due to either of these causes would appear with opposite signs in the two series and be eliminated in the correlations which combine them both. It may be remarked that when the observations are corrected for the systematic displacements to the violet discussed above, the difference between morning and evening series, viewed in the light of the probable error of the observations, is not of an order that would indicate a divergence from the assumed parallax or a rate of rotation higher than that found by Slipher.

2. *Superposed skylight.*—Venus can be seen on the slit of the spectrograph at any time during the day, and some preliminary plates indicate that it may be possible to secure reliable observations in full daylight, provided the relative velocity of Venus and the earth is large enough to separate completely the absorption lines in the spectra of Venus and the sky. When the angle *VSE* is large, however, the displacement due to the relative velocity is less than the width of a line, and wave-lengths measured under such conditions are affected by an error depending on the brightness of the sky and the amount of displacement. This error appears as a shift to the violet when Venus is west of the sun, and to the red when Venus is east of the sun. Tests were made with superposed spectra having different exposures and a relative displacement of 0.120 A. They showed that a superposed spectrum having 5 per cent of the intensity of the primary spectrum was sufficient to produce measurable shifts.

When the angle *VSE* is large, the time available is short, and therefore it is necessary, with Venus east of the sun, to begin the exposures as early as possible and, with the planet west of the sun,

[1] *Lowell Observatory Bulletin*, 1, 9, 1903.

to continue them until the brightness of the sky reaches the permissible limit. To examine our observations for possible effects due to superposed skylight near twilight and dawn, we have selected groups of observations in which the components have approximately equal altitudes but begin at unequal intervals after sunset or end at unequal intervals before sunrise. The effect of altitude is by this arrangement of the observations the same for each group. An examination of the data in Table V reveals no measurable effect due to superposed skylight, even when the exposures were begun at sunset or ended at sunrise, as is shown by the agreement between the components of each group.

TABLE V

ABSENCE OF EFFECT OF SUPERPOSED SKYLIGHT

1919				1919–1920			
Begun after Sunset	No. Plates	h	$\Delta\lambda$	Ended before Sunrise	No. Plates	h	$\Delta\lambda$
min.				min.			
36	5	17°	−0.005	6.3	3	15°	−0.002
15	2	16.5	−0.004	− 1.5	4	14	−0.003
14	6	26	−0.002	13	6	31	−0.001
1.6	8	26	−0.001	− 1	3	37	+0.002

3. *The effects of altitude.*—The spectroscopic conditions arising from low altitude are complex, and the following considerations show that further investigation is required to determine the rôle played by the various factors in producing the observed displacements. The atmospheric dispersion at low altitude displaces the photographic image relative to the visual image very appreciably. When the guiding is done upon the visual image, as in these observations, this relative displacement may produce dissymmetry in the illumination of the slit. At 8° altitude the dispersion between λ 4500 and λ 5700 is 8″, a third of the diameter of the planet at maximum elongation. Campbell found large differences in the radial velocity of Venus when he compared the values obtained by placing the slit just inside the terminator with those obtained

when the slit was just inside the limb.[1] These differences, which he attributed to non-uniform illumination of the slit, reversed in sign when the spectrograph was rotated through 180°. In observations such as ours non-uniform illumination of the slit due to guiding on the visual image would depend not only upon the atmospheric dispersion at low altitude but also upon the diameter of the image relative to the width of the slit. This source of error we hope to eliminate in our next series of observations upon Venus by using a blue screen in the observing telescope, thus making it possible to keep the photographic image symmetrically placed on the slit. We have not yet found a satisfactory reason why rotation of the spectrograph did not reverse the sign of the displacements, as was expected if they are due entirely to non-uniform illumination of the slit.

The refraction, moreover, requires compensation in both right ascension and declination, involving systematic corrective movements of the image on the slit. We were obliged to overcome the drift in declination by a progressive tilt of the concave mirror, a faulty procedure, as the angle of incidence at the grating is very sensitive to changes in the direction of the beam from the concave mirror. This possible source of error will be eliminated from our next observations as motor controls on the second flat now enable the observer to guide by it.

4. *Kodaikanal observations.*—The following Kodaikanal observations are collected from the reports and papers by Evershed:[2]

TABLE VI

VENUS—SKY FROM KODAIKANAL OBSERVATIONS

VSE	45°	62°	67°	75°
V−Sky	+0.0026[3]	−0.0034	−0.0024	−0.0068
VSE	95°	102°	135°	140°
V−Sky	−0.0009	−0.0052	−0.014	−0.007 A

[1] *Lick Observatory Bulletin*, **9**, 30, 1916.

[2] *Kodaikanal Observatory Report*, p. 2, 1917; p. 2, 1918; p. 3, 1919; *Monthly Notices*, **78**, 278, 1918; **79**, 257, 1919; **80**, 395, 1920; *Observatory*, **43**, 156, 1920.

[3] *Kodaikanal Observatory Report*, 1918. Four excellent plates give orbital velocity 3.5 per cent low. *Monthly Notices*, **78**, 279, 1918: 0.45 km/sec. less than orbital velocity. A displacement of +.0067 A is deduced from these statements and averaged with that of the 1918 series.

Observations when the angle *VSE* is 135°–140° are necessarily made with Venus at altitudes of about 10°; near maximum elongation they would most naturally be made at high altitudes; and with *VSE* near 90°, at intermediate altitudes. The altitudes for the Kodaikanal observations are not available, but, if they are near the values suggested as probable, Evershed's observations of V−Sky may also be correlated with altitude. The question is then one of interpretation; plates at high and low altitudes with the same value of *VSE*, and at low altitude with large and small *VSE*, will eventually furnish a definite answer. As far as present observations have a bearing on the question, they indicate that the main factors producing the displacements are those depending upon the low altitude of Venus at the time of observation. When this effect is eliminated, the remaining residuals, which seem to vary with the relative position of earth, Venus, and sun, are more reasonably correlated with the varying diameter of the planet than with the angle *VSE*.

MOUNT WILSON OBSERVATORY
March 1921

BRIGHT AND DARK NEBULAE NEAR ζ ORIONIS PHOTOGRAPHED WITH THE 100-INCH HOOKER TELESCOPE[1]

By JOHN C. DUNCAN

ABSTRACT

Photographs made with the 100-inch Hooker telescope of the Mount Wilson Observatory are reproduced in two plates. They exhibit the following features: the *bright nebulae N.G.C. 2024* and *2023* and *I.C. 431*, *432*, and *434:* the *dark cosmic cloud Barnard 33*, which indents or overlies the nebula I.C. 434; the *great disparity in the number of faint stars* on opposite sides of a line passing nearly north and south through ζ Orionis; and a *striated appearance* in the faint nebulosity west of I.C. 434.

Evidence is given of the existence of *four distinct types of extended masses* in the neighborhood, and suggestions made in explanation of the aspect of the region as presented by the photographs.

The region surrounding the star ζ, at the southeastern end of the Belt of Orion, has been studied on account of its remarkable nebulae by several observers, the first of whom was W. Herschel, who listed it as No. 25 of his fifty-two regions that contain diffuse nebulosity.[2] Six of its nebulae are included by Dreyer in the *New General Catalogue* or the first *Index Catalogue*. Photographs showing many of its interesting features have been published and discussed by W. H. Pickering,[3] Roberts,[4] Wolf,[5] Keeler,[6] Barnard,[7] and Curtis.[8]

During the past winter I have made photographs of this region at the principal focus of the 100-inch Hooker telescope, and the

[1] *Contributions from the Mount Wilson Observatory*, No. 209.

[2] *Philosophical Transactions*, **101**, 276, 1811.

[3] *Annals of Harvard College Observatory*, **32**, 66, and Plate III, Fig. 3, 1895.

[4] *Astrophysical Journal*, **17**, 74, and Plate IV, 1903; also, *Monthly Notices*, **63**, 31, and Plate 1, 1903.

[5] *Monthly Notices*, **63**, 304, and Plate 11, 1903.

[6] *Publications of the Lick Observatory*, **8**, Plate XIII, 1908.

[7] *Astrophysical Journal*, **38**, 500, and Plate XX, Fig. 1, 1913; also *Publications of the Lick Observatory*, **11**, Plate XX, 1913.

[8] *Publications of the Astronomical Society of the Pacific*, **30**, 66, and Plate IV, Fig. 1, 1918; *Publications of the Lick Observatory*, **13**, 23, and Plate II, Fig. 5, 1918.

PLATE XI

N

E

W

BRIGHT AND DARK NEBULAE SOUTH OF ζ ORIONIS
Scale: 1 mm = 14.″0 (0.89 that of original negative)

PLATE XII

N

E

W

ζ Orionis and the Nebulae on the East and North
Scale: 1 mm = 12″.8 (0.81 that of original negative)

great focal length, light-gathering power, and resolving power of this instrument have brought out certain remarkable features with great distinctness. Two of these photographs are reproduced in Plates XI and XII. The original negatives are 8×10 inches in size, but in making the reproductions only the central parts were used and these were reduced in scale. The excellence of the reproductions is due largely to the skill of Mr. Ellerman, who increased the intensity of the images of faint nebulosities by successive copying on slow plates.

PLATE XI.—Center of plate (1920.0), $\alpha = 5^h37^m.0$, $\delta = -2°31'$. 1920, November 13. Exposure three hours. Seeing good, but figure of mirror somewhat imperfect. Seed 23 plate.

The bright star ζ Orionis is just off the north side of the plate, and a bright ray, produced by diffraction of its light by one of the steel supports of the secondary mirror, extends from it toward the south and east. The brightest star shown is D.M. −2°1337, 19 mm from the bottom of the plate and 42 mm from the right side. Its visual magnitude, as given by the *Durchmusterung*, is 7.5.

Almost vertically through the middle of the plate lies the nebula I.C. 434, which was discovered photographically at the Harvard Observatory in 1887.[1] It here appears as the bright fringe of a diffuse nebulosity that fills the western half of the field. This diffuse nebulosity is remarkably striated, the striae lying in a direction approximately east and west. The fringe has numerous branches and irregularities and is suggestive of the edge of a relatively thin sheet that is crumpled and turned edgewise to the observer. Earlier observers have noted the scarcity of faint stars east of the nebulous fringe as contrasted with their great abundance on the west. The effectiveness of the Hooker telescope in photographing faint stars makes this contrast very conspicuous.

In the northeastern corner of the field is the nebula N.G.C. 2023, which surrounds a star of magnitude 8.5, not shown on the plate because of overexposure of the nebula. It is terminated rather abruptly on the west side, and shows a clearly defined dark marking on the east. The existence of spiral rays, noted by the Harvard observers,[2] is not here confirmed.

[1] *Annals of Harvard College Observatory*, **18**, 115, 1890. [2] *Ibid.*, 116, 1890.

By far the most interesting object shown on the plate is the dark cloud near the center, which forms a bay in the bright nebula and which has attracted attention since the earliest photographic observations of the region. It is listed by Barnard as No. 33 of his dark markings of the sky.[1] On the present plate, faint lights appear within the cloud, and a notable silver lining is shown along its western edge. On the original negative the eastern boundary can be traced on the faint background of the sky, and is seen to extend north and east nearly to N.G.C. 2023. An aid to tracing its position is found in the diffracted ray from ζ Orionis, which seems to have been too faint to affect the plate perceptibly by its own light but is plainly visible where the plate has been brought to its threshold by the nebulous background, so that the ray is interrupted where it crosses the dark cloud. A second and much smaller and paler dark bay lies about 15′ north of Barnard 33, near the 8.5 magnitude star D.M. $-2°1343$, and a third about 6′ still farther north.

PLATE XII.—Center of plate (1920.0), $\alpha = 5^h37^m.3$, $\delta = -1°53'$. 1920, December 8. Exposure, 5 hours, 35 minutes. Sky somewhat hazy. Seed 30 plate.

ζ Orionis is near the west side of the plate, where irradiation has spread its light into a great blot. The star may be located accurately at the intersection of the rays produced by the mirror supports. At the extreme northwest corner of the plate is the nebula I.C. 431, and 10′ east of this is I.C. 432. These nebulae surround the stars D.M. $-1°1001$ and $-1°1005$ respectively, stars of about 8.5 visual magnitude. A few of the stars that lie near the north edge of Plate XI appear also near the south edge of Plate XII. The continuation of the nebula I.C. 434 toward ζ may be seen on Plate XII, which shows also that the disparity in the number of faint stars on the east and west sides of the nebulous fringe continues some distance north of ζ, where the line of division seems to turn somewhat toward the west.

The greater part of Plate XII is occupied by the remarkable nebula N.G.C. 2024, discovered in 1786 by W. Herschel, who described it[2] as a "remarkable nebulosity, divided in 3 or 4 large

[1] *Astrophysical Journal*, **49**, 14, 1919.

[2] *Philosophical Transactions*, **79**, 248, 1789.

patches including a dark space." The brightest parts cover a space some 25′ in diameter, and there are faint extensions, one of which reaches as far as I.C. 432 on the northwest. Both this nebulosity and that of I.C. 434 can be traced on the original plate to within 5′ of ζ Orionis, where they are concealed in the glare about the bright star. The irregularities of the bright and dark markings of N.G.C. 2024 are such as to defy description, which fortunately is unnecessary, as they are well shown in the illustrations. The character of this nebulosity appears to be different from either that of I.C. 434 or that of the neighboring nebulous stars.

A study of the photographs of this region tends to the conviction that we have here to do with extended masses of not less than four distinct types: (1) the ropy, branching nebulosity of I.C. 434; (2) the nebulosity of N.G.C. 2024; (3) the nebulous stars N.G.C. 2023 and I.C. 431, 432, and 435;[1] (4) dark nebulosities, best exemplified by the cloud Barnard 33.

The phenomena shown suggest the following speculations: Perhaps the fringe of I.C. 434 represents the common boundary of a dense, dark mass on the east and a body of thin, luminous nebulosity on the west. These two masses may have a relative motion toward each other, which results in a concentration of the bright nebulosity along the line of contact, this concentrated nebulosity being the fringe. The faint nebulosity west of the fringe must be sufficiently transparent to transmit the light of the starry background, while the dark material on the east obscures all the stars behind it. The bright nebula N.G.C. 2024 seems to be of the nature of a bright outcropping of the dark nebula, which indeed is probably nowhere absolutely non-luminous unless it be so in the darkest part of Barnard 33. Perhaps the four stars that show nebulous burs—D.M. $-1°1001$, $-1°1005$, $-2°1345$, and $-2°1350$—are imbedded in the dark nebula and illuminate that part of it which lies immediately around them, the nebulosities of the third type being due in part to this cause and in part to the same cause as those of the second type. We may suppose the non-nebulous stars that appear east of I.C. 434 to lie between the observer and the dark nebula.

[1] The nebula I.C. 435 is some 20′ east of N.G.C. 2023 and is not shown in the illustrations. It surrounds the 8.5 magnitude star D.M. $-2°1350$.

Mr. E. P. Hubble has kindly loaned me a plate made by him with the Hooker telescope 1920, November 18, which shows the region immediately north of ζ Orionis. The line of cleavage between the regions of few and of many stars is clearly marked on this plate, and passes in a zigzag fashion northwest of ζ nearly to I.C. 431, where it bends toward the west and returns, forming a bay about 15′ deep, and then passes northeastward to a point near the sixth-magnitude star $-1°1004$, about 1° north of ζ and near the north edge of the plate. There is on this plate no hint of a nebulosity similar to I.C. 434, and the line of cleavage has not here the regularity that is noticeable in that part of it lying south of ζ. Long-exposure photographs of the Orion region made with the 10-inch Cooke refractor of this observatory by Mr. Hubble and Mr. Pettit indicate that the obscuring mass east of ζ Orionis is only a part of a much larger region that extends several degrees toward the northeast, enveloping the bright nebula Messier 78, and also, though less plainly, some distance toward the south. The general outlines of this dark region can be traced on the Franklin-Adams chart.

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March 1921

INDEX TO VOLUME LIII

SUBJECTS

PAGE

Abstracts, Preparation of 231

Algol, a Photo-Electric Study of. *Joel Stebbins* 105

R Aquarii, Observations of the Nebular Lines in the Spectrum of the Long-Period Variable Star. *Paul W. Merrill* 375

Arc, Pressure-Shifts in a Calcium. *L. F. Miller* 224

Bismuth Lines, Structure of the. *H. Nagaoka* and *Y. Sugiura* . . . 339

Calcium Arc, Pressure-Shifts in a. *L. F. Miller* 224

RS Canum Venaticorum, Provisional Elements of the Eclipsing System. *Bancroft Walker Sitterly* 99

Carbon in Spectroscopy, Use of a Lime Cathode of. *Y. Sugiura* and *T. Matoba* 323

Carbon, Iron, and Nickel, Vacuum-Spark Spectra in the Extreme Ultra-Violet of. *R. A Millikan, I. S. Bowen*, and *R. A. Sawyer* . . . 150

SX Cassiopeiae, Elements of the Eclipsing System. *Mary Fowler* . 165

Classification of Long-Period Variables, Geometrical. *J. G. Hagen* . 179

Contributors, Notice to 168

65 τ Cygni, Orbit of the Short-Period Spectroscopic Binary. *J. S. Paraskévopoulos* 144

X Cygni, Spectroscopic Orbit of the Cepheid Variable. *John C. Duncan* 95

Diameter of α Orionis with the Interferometer, Measurement of the. *A. A. Michelson* and *F. G. Pease* 249

Dispersion, to Account for the Change of Refractive Index with Temperature, a Modification of the Electron Theory of. *G. Szivessy* . . 326

Electron Theory of Dispersion, to Account for the Change of Refractive Index with Temperature, a Modification of the. *G. Szivessy* . . 326

Grating and Interferometer Measures λ 3370–λ 6750, Wave-Lengths of Lines in the Iron Arc from. *Charles E. St. John* and *Harold D. Babcock* 260

Hydrogen Chloride, Absorption Spectrum of. *Walter F. Colby* and *Charles F. Meyer* 300

Images, Mutual Action of Adjacent Photographic. *Frank E. Ross* . 349

Infra-Red Spectrum of the Sun λ 8900–λ 9900, Examination of the. *Frederick S. Brackett* 121

Interferometer, Measurement of the Diameter of α Orionis with the. *A. A. Michelson* and *F. G. Pease* 249

Interferometer Measures λ 3370–λ 6750, Wave-Lengths of Lines in the Iron Arc from Grating and. *Charles E. St. John* and *Harold D. Babcock* 260

PAGE

Iron, and Nickel, Vacuum-Spark Spectra in the Extreme Ultra-Violet of Carbon. *R. A. Millikan, I. S. Bowen*, and *R. A. Sawyer* . . . 150
Iron Arc from Grating and Interferometer Measures λ 3370–λ 6750, Wave-Lengths of Lines in the. *Charles E. St. John* and *Harold D. Babcock* . . . 260
Lime Cathode of Carbon in Spectroscopy, Use of a. *Y. Sugiura* and *T. Matoba* . . . 323
Lines, Structure of the Bismuth. *H. Nagaoka* and *Y. Sugiura* . . 339
Lines in Spectra of Venus, Systematic Displacements of. *Charles E. St. John* and *Seth B. Nicholson* . . . 380
Lockyer, Sir Norman, 1836–1920. *A. L. Cortie, S.J.* . . . 233
Magnetic Separation, Measurement of Pole-Effect and Its Connection with. *H. Nagaoka* . . . 329
Manganese, Variation with Temperature of the Electric Furnace Spectrum of. *Arthur S. King* . . . 133
Motions, Radiation Pressure and Celestial. *Henry Norris Russell* . . 1
Nebula, On the Passage of a Star through a. *Ernest W. Brown.* . . 169
Nebulae near ζ Orionis Photographed with the 100-Inch Hooker Telescope, Bright and Dark. *John C. Duncan* . . . 392
Nebular Lines in the Spectrum of the Long-Period Variable Star R Aquarii, Observations of the. *Paul W. Merrill* . . . 375
Nickel, Vacuum-Spark Spectra in the Extreme Ultra-Violet of Carbon, Iron, and. *R. A. Millikan, I. S. Bowen*, and *R. A. Sawyer* . . . 150
Notice to Contributors . . . 168
Orbit of the Cepheid Variable X Cygni, Spectroscopic. *John C. Duncan* 95
Orbit of the Short-Period Spectroscopic Binary 65 τ Cygni. *J. S. Paraskévopoulos* . . . 144
Orbits of Seven Spectroscopic Binaries. *R. F. Sanford* . . . 201
Orion, Suspected Variable, Bond 624, in Trapezium of. *J. A. Parkhurst* 317
α Orionis with the Interferometer, Measurement of the Diameter of. *A. A. Michelson* and *F. G. Pease* . . . 249
ζ Orionis Photographed with the 100-Inch Hooker Telescope, Bright and Dark Nebulae near. *John C. Duncan* . . . 392
Parallaxes of 1646 Stars Derived by the Spectroscopic Method. *W. S. Adams, A. H. Joy, G. Strömberg*, and *Cora G. Burwell* . . . 13
Photo-Electric Study of Algol. *Joel Stebbins* . . . 105
Photographic Images, Mutual Action of Adjacent. *Frank E. Ross* . . 349
Pole-Effect and Its Connection with Magnetic Separation, Measurement of. *H. Nagaoka* . . . 329
Pressure and Celestial Motions, Radiation. *Henry Norris Russell* . 1
Pressure in the Atmospheres of the Stars. *P. Salet* . . . 327
Pressure-Shifts in a Calcium Arc. *L. F. Miller* . . . , 224
Prominence of October 8, 1920, Exceptionally High Solar. *Oliver J. Lee* 310
Radiation Pressure and Celestial Motions. *Henry Norris Russell* . . 1

PAGE

Refractive Index with Temperature, a Modification of the Electron Theory of Dispersion, to Account for the Change of. *G. Szivessy* . 326

Solar Prominence of October 8, 1920, Exceptionally High. *Oliver J. Lee* 310

Spectra, Intensity Differences in Furnace and Arc among the Component Series in Band. *Arthur S. King* 161

Spectra in the Extreme Ultra-Violet of Carbon, Iron, and Nickel, Vacuum-Spark. *R. A. Millikan, I. S. Bowen,* and *R. A. Sawyer* 150

Spectra of Class Md, Characteristic Behavior of the Bright Lines in Stellar. *Paul W. Merrill* 185

Spectra of Venus, Systematic Displacements of Lines in. *Charles E. St. John* and *Seth B. Nicholson* 380

Spectroscopic Binaries, Orbits of Seven. *R. F. Sanford* 201

Spectroscopic Binary 65 τ Cygni, Orbit of the Short-Period. *J. S. Paraskĕvopoulos* 144

Spectroscopy, Use of a Lime Cathode of Carbon in. *Y. Sugiura* and *T. Matoba* 323

Spectrum of Hydrogen Chloride, Absorption. *Walter F. Colby* and *Charles F. Meyer* 300

Spectrum of Manganese, Variation with Temperature of the Electric Furnace. *Arthur S. King* 133

Spectrum of the Long-Period Variable Star R Aquarii, Observations of the Nebular Lines in the. *Paul W. Merrill* 375

Spectrum of the Sun, λ 8900–λ 9900, Examination of the Infra-Red. *Frederick S. Brackett* 121

Star through a Nebula, On the Passage of a. *Ernest W. Brown* . . 169

Stars, Pressure in the Atmospheres of the. *P. Salet* 327

Sun, λ 8900–λ 9900, Examination of the Infra-Red Spectrum of the. *Frederick S. Brackett* 121

Temperature, a Modification of the Electron Theory of Dispersion, to Account for the Change of Refractive Index with. *G. Szivessy* . 326

Temperature of the Electric Furnace Spectrum of Manganese, Variation with. *Arthur S. King* 133

Ultra-Violet of Carbon, Iron, and Nickel, Vacuum-Spark Spectra in the Extreme. *R. A. Millikan, I. S. Bowen,* and *R. A. Sawyer* . . 150

Variable, Bond 624, in Trapezium of Orion, Suspected. *J. A. Parkhurst* 317

Variable Star R Aquarii, Observations of the Nebular Lines in the Spectrum of the Long-Period. *Paul W. Merrill* 375

Variable X Cygni, Spectroscopic Orbit of the Cepheid. *John C. Duncan* 95

Variables, Geometrical Classification of Long-Period. *J. G. Hagen* . 179

Venus, Systematic Displacements of Lines in Spectra of. *Charles E. St. John* and *Seth B. Nicholson* 380

Wave-Lengths of Lines in the Iron Arc from Grating and Interferometer Measures λ 3370–λ 6750. *Charles E. St. John* and *Harold D. Babcock* 260

INDEX TO VOLUME LIII

AUTHORS

PAGE

ADAMS, W. S., A. H. JOY, G. STRÖMBERG, and CORA G. BURWELL. Parallaxes of 1646 Stars Derived by the Spectroscopic Method . 13

BABCOCK, HAROLD D., and CHARLES E. ST. JOHN. Wave-Lengths of Lines in the Iron Arc from Grating and Interferometer Measures λ 3370–λ 6750 260

BOWEN, I. S., R. A. SAWYER, and R. A. MILLIKAN. Vacuum-Spark Spectra in the Extreme Ultra-Violet of Carbon, Iron, and Nickel 150

BRACKETT, FREDERICK S. Examination of the Infra-Red Spectrum of the Sun, λ 8900–λ 9900 121

BROWN, ERNEST W. On the Passage of a Star through a Nebula . 169

BURWELL, CORA G., W. S. ADAMS, A. H. JOY, and G. STRÖMBERG. Parallaxes of 1646 Stars Derived by the Spectroscopic Method . 13

COLBY, WALTER F., and CHARLES F. MEYER. On the Absorption Spectrum of Hydrogen Chloride. 300

CORTIE, A. L., S.J. Sir Norman Lockyer, 1836–1920 233

DUNCAN, JOHN C. Bright and Dark Nebulae near ζ Orionis Photographed with the 100-Inch Hooker Telescope 392

Spectroscopic Orbit of the Cepheid Variable X Cygni 95

FOWLER, MARY. Elements of the Eclipsing System SX Cassiopeiae . 165

HAGEN, J. G. On the Geometrical Classification of Long-Period Variables 179

JOY, A. H., G. STRÖMBERG, CORA G. BURWELL, and W. S. ADAMS. Parallaxes of 1646 Stars Derived by the Spectroscopic Method . 13

KING, ARTHUR S. Intensity Differences in Furnace and Arc among the Component Series in Band Spectra 161

The Variation with Temperature of the Electric Furnace Spectrum of Manganese 133

LEE, OLIVER J. Exceptionally High Solar Prominence of October 8, 1920 310

MATOBA, T., and Y. SUGIURA. Use of a Lime Cathode of Carbon in Spectroscopy 323

MERRILL, PAUL W. Characteristic Behavior of the Bright Lines in Stellar Spectra of Class Md 185

Observations of the Nebular Lines in the Spectrum of the Long-Period Variable Star R Aquarii 375

MEYER, CHARLES F., and WALTER F. COLBY. On the Absorption Spectrum of Hydrogen Chloride 300

PAGE

MICHELSON, A. A., and F. G. PEASE. Measurement of the Diameter of α Orionis with the Interferometer 249
MILLER, L. F. Pressure-Shifts in a Calcium Arc 224
MILLIKAN, R. A., I. S. BOWEN, and R. A. SAWYER. Vacuum-Spark Spectra in the Extreme Ultra-Violet of Carbon, Iron, and Nickel . 150
NAGAOKA, H. On the Measurement of Pole-Effect and Its Connection with Magnetic Separation 329
NAGAOKA, H., and Y. SUGIURA. Structure of the Bismuth Lines . . 339
NICHOLSON, SETH B., and CHARLES E. ST. JOHN. Systematic Displacements of Lines in Spectra of Venus 380
PARASKÉVOPOULOS, J. S. Orbit of the Short-Period Spectroscopic Binary 65 τ Cygni 144
PARKHURST, J. A. Suspected Variable, Bond 624, in Trapezium of Orion 317
PEASE, F. G., and A. A. MICHELSON. Measurement of the Diameter of α Orionis with the Interferometer 249
ROSS, FRANK E. Mutual Action of Adjacent Photographic Images . 349
RUSSELL, HENRY NORRIS. Radiation Pressure and Celestial Motions . 1
ST. JOHN, CHARLES E., and HAROLD D. BABCOCK. Wave-Lengths of Lines in the Iron Arc from Grating and Interferometer Measures λ 3370–λ 6750 260
ST. JOHN, CHARLES E., and SETH B. NICHOLSON. Systematic Displacements of Lines in Spectra of Venus 380
SALET, P. On the Pressure in the Atmospheres of the Stars . . . 327
SANFORD, R. F. Orbits of Seven Spectroscopic Binaries 201
SAWYER, R. A., R. A. MILLIKAN, and I. S. BOWEN. Vacuum-Spark Spectra in the Extreme Ultra-Violet of Carbon, Iron and Nickel . 150
SITTERLY, BANCROFT WALKER. Provisional Elements of the Eclipsing System RS Canum Venaticorum 99
STEBBINS, JOEL. A Photo-Electric Study of Algol 105
STRÖMBERG, G., CORA G. BURWELL, W. S. ADAMS, and A. H. JOY. Parallaxes of 1646 Stars Derived by the Spectroscopic Method . 13
SUGIURA, Y., and T. MATOBA. Use of a Lime Cathode of Carbon in Spectroscopy 323
SUGIURA, Y., and H. NAGAOKA. Structure of the Bismuth Lines . . 339
SZIVESSY, G. A Modification of the Electron Theory of Dispersion, to Account for the Change of Refractive Index with Temperature . 326

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